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<p>A synopsis of the sponsored arctic technology development at the University of Washington is presented. This includes a description of the technical management plan which has been used to administer the program; final reports from the four technical investigations that were undertaken (the design of an unmanned, untethered arctic research submersible, the study of arctic research missions for surface effect vehicles, the experimental development of a lightweight peck-ice shelter module and the experimental development of a thermal ice-coring mechanism); and a description of several concepts for new arctic technology which are being considered. (U)</p>		

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# ARCTIC TECHNOLOGY DEVELOPMENT AT THE UNIVERSITY OF WASHINGTON

## Annual Report

1 June 1970 - 30 June 1971

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ARCTIC TECHNOLOGY DEVELOPMENT  
AT THE UNIVERSITY OF WASHINGTON  
ANNUAL REPORT

**I. INTRODUCTION**

The University of Washington has had an active scientific interest in the Arctic for nearly four decades. During the past year this has been enhanced by a strong effort in Arctic technology as a result of the current ARPA program. At the outset of that program we identified three long-range objectives in Arctic Technology as follows:

1. To provide a growing set of technological alternatives for conducting work in the Arctic regions.
2. To provide a basis for a systematic consideration of Arctic problems by multidisciplinary academic teams.
3. To provide the framework within which the needs for technological advancements in marine-related activities can be identified in terms of alternate solutions to specific problems.

The specific tasks selected to initiate the program were:

1. To provide an administrative structure within the University's Division of Marine Resources (DMR) through which problems could be identified and systematic responses developed.
2. To accomplish the design of a portable, unmanned Arctic submersible, together with its control and data acquisition systems for research missions beneath the ice canopy.
3. To explore the potential of a surface effect vehicle for Arctic research missions.

As we stand at the conclusion of the first year of effort we are pleased to report that we have been able to accomplish considerably more than was originally anticipated. Highlights of this year's activity are listed below with much greater detail provided in later sections of this report.

1. An administrative mechanism for the program has been established to assure its timely and coordinated accomplishment and to provide a continuing source of new concepts for the improvement of polar research. These functions are carried out under the guidance of an Arctic Technology Advisory Committee (ATAC) which pools the University expertise in cold regions research.

2. The design of the Unmanned Arctic Research Submersible (UARS) system was completed on schedule without technical delays or difficulty. A review of this work was conducted in early December, 1970, to acquaint the scientific community with the concept and an interim design report was prepared at that time.

3. The study of surface effect vehicle research missions has been completed and recommendations made for carrying out a valid Arctic vehicle test program. Suggested SEV design characteristics for two Arctic research missions also have been provided.

4. Within the area of peripheral Arctic technology a significant contribution was made in developing and demonstrating a hot water ice coring device. This technique, originally planned for the support of UARS in 1972, is now scheduled for use this summer in a Naval Ordnance Laboratory project. In another project, a light-weight, prefabricated Arctic living and research module for use on pack ice was designed and carried through experimental development.

ARPA sponsorship of this Technology Program has had a pronounced effect in catalyzing new ideas from within the University. For example, as a spin-off from the UARS tracking system design has emerged an Arctic data buoy concept which will be suitable for use in both the frozen central pack ice and in the marginal seas. Also, the design of the UARS acoustic ice profiler led to a concept for acoustic instrumentation to measure permafrost thickness and internal discontinuities. Many other new ideas and approaches have been generated for the Arctic. Some of the more promising ones are described in this report under PROGRAM ACTIVITY FORECAST.

The Arctic Technology Program at the University of Washington has provided ARPA with continuing access to an interdisciplinary source of recognized Arctic competence. This broadly qualified group of Arctic scientists and engineers functions through the Arctic Technology Advisory Committee which is on call to address problems of immediate concern to ARPA, DDR&E and other DOD offices. This year members of this group attended and contributed to two ARPA-sponsored Arctic workshops and participated in a mid-contract design review of the UARS system. The committee holds bi-monthly meetings to assure coordination of all Arctic activity at the University and to review proposals for the development of new technology. The ARPA Arctic workshops at Hanover and Arlington highlighted many areas where advanced technological concepts are needed. We have focused attention on at least two of these -- long-life, remotely interrogated, under-ice data buoys, and electromagnetic detection techniques and surveillance of the sea-ice surface (brief concept description given in PROGRAM ACTIVITY FORECAST).

The University is, naturally, interested in the broadest application of Arctic technology to research and the public benefit. This program is viewed as a very desirable approach to this philosophy for clearly the same equipment,

developed to locate a commercial aircraft forced down in the Arctic night, would be suitable to study the military aspects of electromagnetic signature suppression and other camouflaging needs for surface forces. Similarly, an instrument that can be developed to assess permafrost areas for commercial building sites differs little from that which is needed by military engineers to permit the quick selection of Arctic cantonment areas.

## II. ANNUAL PERFORMANCE SUMMARY

A full technical description and discussion of each project within this program is provided in the appendices. However, in consideration for those readers who are interested primarily in a synopsis of the work in this year's projects this section has been included.

### A. UNMANNED ARCTIC RESEARCH SUBMERSIBLE SYSTEM

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W. E. Nodland (206) 543-1319

The design and principal subsystem development for an Unmanned Arctic Research Submersible (UARS) system was completed under this contract. The system consists of two major elements -- an unmanned submersible which serves as a mobile instrument carrier, and a remote, acoustically controlled tracking, guidance, and recovery system. The vehicle weighs approximately 1000 pounds, has a length of approximately 10 ft, a diameter of 19 inches and may be driven at different speeds depending upon the mission to be accomplished. Oceanographic measurements are usually taken at six knots while ice under-surface profiling is done at three knots. The main batteries will supply up to ten hours of run time. The principal acoustic components carried by the vehicle are for communication, tracking, homing and collision avoidance. The latter is made necessary because of the potential presence of massive ice keels that could project downward into the path of the oncoming submersible. The design maximum operating depth of the submersible is 1500 feet. The initial instrumentation suite of UARS will also feature acoustic sensors incorporated into an ice profiler that is capable of measuring under-surface elevations to a differential accuracy of 0.25 feet from a vehicle depth of 60 to 250 ft. below the surface. The launching procedure calls for the vehicle to be lowered by special sling through a 4 x 12 foot hole in the ice and released from a horizontal position at a depth of approximately 50 feet. Procedures and equipment developed to facilitate making the access hole in the ice will be described in a later section.

Tracking elements in the system are (1) an array of three or more RF-telemetering hydrophones arranged in a pattern which defines the experiment or survey area, (2) two baseline acoustic projectors which are normally located within the survey area and provide a coordinate reference system, (3) an acoustic source aboard UARS and (4) the timing units, data processors and power supply which provide the basis for interpreting the acoustic signals and making rapid position calculations. The hydrophones and baseline projectors are designed as free-floating buoys, but can be frozen in place, weather permitting.

In order to control the UARS precisely and to insure its reliable recovery, an acoustic communication link with the vehicle is employed. The system utilizes a common frequency for command, tracking, and vehicle data transmission. Both the tracking and command pulses are digitally coded using 100 percent phase-shift-keyed modulation at a carrier frequency of 50 kHz. Sixteen command functions are available to control UARS. Because of the large amount of information to be acoustically telemetered to the tracking station, and because of the restriction on pulse length (to avoid multiple path interference), additional coded pulses will be transmitted between tracking pulses.

The basic recovery technique is to lure the vehicle back to the recovery hole by means of an acoustic homing system installed in the vehicle. This system responds to a particular signal that is transmitted from a homing beacon centered in a capture net. This net will be lowered through the ice hole to the operating depth of the submersible and UARS will be commanded to seek the homing signal.

Internally programmed homing logic, an inertial and depth-sensing guidance system, and the command/tracking receivers provide UARS with great retrieval redundancy. However, in the event of massive power interruption or other catastrophic failure a further retrieval capability is provided. The submersible is positively buoyant and will rise to the under-surface of the ice and automatically lower an acoustic beacon and release a dye marker to aid an over-the-ice search party.

To avoid collision with deep pressure ridge keels, the vehicle is equipped with an obstacle avoidance sonar. Pulse length broadening, a characteristic of the expected return from the ridge keels, will be used for pulse validation. This will allow easy rejection of fish echoes. The rapid attenuation at this frequency allows a high pulse repetition rate (five pulses per second) so that obstacle avoidance logic can be based upon receipt of multiple valid returns. The sonar beam is axially directed and is of sufficient width to encompass normal pitch oscillations and trim conditions of UARS. When an obstacle is detected, the vehicle dives to a deeper pre-programmed depth. After the obstacle is passed, the vehicle can be commanded to return to the original depth if desired.

The pressure hull is designed for a maximum operating depth of 1500 feet with a calculated crush depth of 2800 feet. In the design of pressure hulls, internal volume, shape, construction material, depth capability, weight and payload capability are factors involved in a trade-off analysis. In this case, the hull size was determined principally by the space requirements of the components to be carried in the hull. The vehicle comprises five small sections -- a pressure hull consisting of four sections and a flooded tail-cone section. The vehicle can be broken down into individual sections for shipment to and from the test site. It will thus be possible to transport the vehicle out onto the ice pack by light aircraft, even though it will take more than one trip. Normal servicing between runs is accomplished by

separating the vehicle at the joint just aft of the battery section. This provides access to the battery for charging or replacement; to the data chassis and to the power control panel on the front of the data chassis where the switches are located for starting the vehicle, calibrating the instruments, initializing the gyro and performing control system checkout. The data chassis, control chassis and battery are mounted on slides within rails fixed to the hull so that they can be easily removed for servicing.

The propulsion motor horsepower requirement (1/4 hp) was determined using drag values and estimates of propeller and gear train efficiency at a vehicle speed of three knots. This was specified by the initial research mission of the vehicle. Silver-zinc batteries will be used because their high energy density matches the need for the vehicle to be as small and light as possible to facilitate portability and handling. For increased reliability the vehicle will carry two battery supplies- a main and reserve unit. As mentioned previously, the main battery will provide a normal 10-hour run capability. Should the main battery fail, the reserve unit will automatically switch on and provide slightly more than two hours of run time to enable the vehicle to return to its recovery hole or an open lead.

The ice profiling sub-system receiving transducer is a spherical, two-component acoustic lens, with a raster of transducers located in the focal surface. In operation, the profiling transmitter transducer, (which is located just forward of the multibeam receiver transducer) is pulsed and the reflected signal in the direction of the receiving beams is detected. The overall signal transit time provides a measurement of slant range. The "fan" of multiple beams is oriented perpendicular to the direction of motion of the vehicle. Normally, the submersible will operate about 50 to 60 feet below the ice, at which depth the insonified area associated with the reflected signal is about one square foot. Thus, with a vehicle speed of three knots and a recording rate of five "data sets" per second it will be possible to obtain essentially continuous surface sampling.

The data recording system is designed to operate with a low-speed magnetic tape recorder in order to obtain high resolution, high density data over long periods of time. All data are recorded in binary form using nine tracks on 1/2-inch magnetic tape. The tape format was designed specifically to minimize the amount of recording electronics and still allow processing with standard IBM equipment. All UARS acoustic subsystems have been successfully tested in the Arctic under-ice environment. Extensive changes in the homing system logic were found necessary to avoid ambiguities arising from reflections from under-ice protrusions. Raw data recording of the hydrophone outputs and other points in the prototype system has allowed the development and laboratory test of the additional logic functions.

## **B. SURFACE EFFECT VEHICLE MISSION AND TECHNOLOGY STUDY**

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This report presents analyses of potential Arctic scientific Surface Effect Vehicle (SEV) missions; available engineering design data; Arctic SEV test experience and preliminary design specifications for two scientific mission profiles in the Arctic. In order to select the most useful application for SEVs in Arctic research many recognized scientists were interviewed. From their responses regarding the utility of SEVs for their investigations, it became apparent that a) scientists would use any machine in which they had confidence; b) no clearly defined research projects could be identified requiring high-speed travel over large distances on the ice pack; c) the effects of the vehicle's own environment on potential experiments in which it would serve as the mobile platform are completely unknown; and d) many scientists felt that their immediate goals did not justify the expense involved in developing an Arctic SEV solely for research missions.

Without more specific guidance the investigators selected two potential scientific mission profiles in order to develop preliminary SEV designs and aid in the subsequent SEV technology evaluation. One of these missions focused on the AIDJEX Program (Arctic Ice Dynamics Joint Experiment) which appears to be representative of a majority of current research needs. A second class of missions falls into the general supply category, hence leading to an Arctic research logistics vehicle. Since large supply operations in the Arctic have been carried out to date with C-130 aircraft, most load requirements for the logistics vehicle were related to C-130 capabilities.

The current (state-of-the-art) engineering data available for the design of new surface effect vehicles for the Arctic environment was next reviewed and severe deficiencies were found to exist in actual flight test verification of the theoretical design curves used in performance analysis. Evaluation of the limited data available on Arctic SEV operations indicated degradations of speed and range capability of as much as 50 percent of theoretical predictions. The paucity of specific engineering design data for use in predicting future designs has lead the investigators to recommend a set of tests which are considered to be an essential link in developing new concepts and technology for Arctic vehicles.

The results of the two preliminary designs showed clearly that it is difficult to obtain good range characteristics in vehicles having low speed capability and low unit surface loading. It would usually be acceptable for a vehicle on the ice to have these performance characteristics since the actual speed at which the vehicle progresses will likely be determined by physical features of the pack ice itself rather than vehicle propulsion capability.

Since this contradicts the design results, i.e., SEVs must have high loadings and go fast to reflect the highest ton-mile efficiencies, it can be generally concluded that unless other attributes of the vehicle (its amphibious capability, loading flexibility, etc.) can compensate for craft inefficiencies at low speeds one would be well advised to seek alternatives to the small and medium size SEV for support use in the Arctic.

#### C. THERMAL ICE CORER \*

Co-principal Investigators: R. E. Francois (206) 543-1357  
E. A. Pence (206) 543-1274

Perhaps the most fundamental requirement for performing work through the polar pack ice is the ability to cut access holes through the ice to the liquid surface wherever required. For the UARS application particularly, we needed the capability to make large (4 x 12 foot) openings for launch and recovery. Holes must also be made for inserting the tracking system acoustic transducers, and a non-destructive technique is required for recovering these instruments after they have become frozen in the ice.

Our approach to the ice holing problem was to use thermal energy to melt an annular groove or pattern of linear grooves in the ice. If a groove of closed geometry is cut completely through the ice, the core (or instrument buoy) may be removed by lifting it out or disposed of by pushing it downward through the ice and out the bottom of the hole. In the case of an ice core, pushing it down through the hole requires about 1/8 the maximum force and 1/4 the energy involved in lifting it out. Furthermore, a man can push down with a force equal to his weight whereas his lifting ability is limited to a force of about half his weight. As an example, a 200 pound man can push out a core 10 feet long with a cross sectional area of 3 square feet.

The technique employed to melt the desired groove utilizes warmed water brought into direct contact with sea ice. This warm water is delivered to a distribution manifold of the desired shape and the melt water is recovered by a suction intake which is mounted directly above the delivery manifold. The excess melt water is discarded and heat is supplied to the remaining water which is then recirculated. The groove is essentially "dry" until some section penetrates the under-surface of the ice. The dry groove therefore, eliminates the possibility of the core refreezing to the ice. The object of our preliminary experiments was to verify the feasibility of this approach in the Arctic environment and to determine the manifold configuration, flow rates, and suction intake elevation for best coring speed.

The experimental apparatus consisted of a pan with vertical tubular vents, sized to fit over a modified three-burner Coleman gasoline stove which transferred approximately 25,000 BTU per hour to the working fluid. A 3-gallon

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\* further discussion is contained in Appendix A



fuel tank was also provided. A pair of small electric-motor-driven pumps (approximately 2 gpm at 5 ft head) were used to pump heated water by hose to the coring manifold and to return the working fluid (also by hose) to the heating pan. The heat source, pan and pump system were mounted in an insulated open-top box so arranged that snow could be melted to facilitate start-up, and initial waste heat would warm the motor-pumps. The hoses were natural rubber wrapped in "space blanket" insulation and covered with a protective, waterproof plastic sheath. An electric heating cable was wound directly on the hoses under the insulation so that the hoses could be thawed if frozen.

Our first experiment at Barrow, Alaska utilized a 10-inch square coring manifold. It was fabricated of 1-inch thin-walled steel pipe. Forty-eight small exit holes were drilled along the contact line of the manifold for uniform distribution of the warm water. A 1/2-inch diameter suction return nozzle was mounted above the manifold. The apparatus was set up in the middle of a salt water lagoon adjacent to the Naval Arctic Research Laboratory. Snow to start the system was melted and brought to 160°F in about 30 minutes. Cutting was then started and a 4 ft. long core removed 45 minutes later. During the operation of this test, the temperature difference between suction and delivery was 22°F. Water was delivered at 72°F. The water level was kept well above the suction intake (by varying pump speed) at all times. Later tests indicated the desirability of keeping the water level as low as possible in the hole. At Ice Island T-3, a hole about 15 in. square was made in 15-1/4 ft of sea ice in 6-1/2 hours. The core had 47 lb. of buoyancy and was easily pushed out through the bottom to leave a clear working hole. During the cutting process it was observed that the core was eroded by water circulating toward the suction intake. The erosion represented an unnecessary expenditure of thermal energy by the system so it was eliminated by mounting an intake manifold similar to the delivery or coring manifold directly above the latter, allowing approximately 1/4-inch clearance between the two tubes. Both a square cutting head and a linear cutting bar 3-1/2 feet long were fabricated in this manner and successfully used in other tests at T-3.

The experimental system performed near the theoretical limits implicit in the thermodynamic principle involved. The "dry hole" approach proved effective even though operations were accomplished with ice and ambient temperatures (at the surface) as low as -27°F. During all of the tests, the very modest heat source which we used consistently cut a 2-inch wide slot whose length-depth product exceeded 10 square feet per hour.

An ice corer design is now being prepared utilizing propane as a fuel source instead of gasoline and having an energy output about 6 times greater than the experimental device. The heater and associated pump equipment will be contained in roughly a 30-inch cube and weigh about 300 lbs. Such a system should allow melting a 2-inch groove whose length-depth product is in excess of 50 feet<sup>2</sup> per hour.



#### **D. POLAR\* MODULE INVESTIGATION**

**Principal Investigator: Vette Jorgensen (206) 543-6600**

In the Arctic Ocean the choice of shelter depends to a high degree on the duration of the stay on the ice field. For a few days a mountain climber tent or a snow shelter might be satisfactory whereas for a longer period of time improved conditions would be required. The insulated tent with plywood floor, such as the Jamesway tent, would be sufficient through months, but in a camp with a useful time of half or full years, shelters with solid walls would usually be preferred.

Shelters with solid walls can be built up of pre-cut materials, or of prefabricated panels, or they can consist of room modules or of trailer-sized buildings. Traditional construction with pre-cut materials will require more construction time at the field station (final site) than any of the other methods and will also often require a covered, heated work area. This increases the costs to the extent that this method will usually not be considered for ordinary sleeping or laboratory shelters.

For locations which can be reached by large freight aircraft such as the C-130 Hercules, and which have heavy road construction equipment for hauling and pushing relatively heavy and large objects the use of trailer sized buildings might be preferred. They arrive fully equipped, can be used immediately and no special construction crew is needed.

For areas which can only be reached by smaller aircraft a construction method based on pre-fabricated panels seems appropriate. The disadvantages with this method as it is used on the U.S. drifting stations today is that usually a construction crew is needed for assembly of the panels and that the total weight of the building type is so large that they can only be moved by heavy bulldozers.

For areas which can or must be reached by medium sized and large helicopters (e.g., the marginal ice zone) a building system based on light-weight room modules would probably provide the best solution. This report describes the design and construction of such a room module system. The goal of this project was to design room modules which could be transported by medium sized helicopters and then easily connected with each other. A survey of existing prefabricated huts made both for commercial and military purposes did not reveal any system which satisfied the above mentioned design goal. A careful search for existing concepts in the fields of housetrailer, ships, airplanes, large (heavy) containers, and smaller (light weight) military transportation cases was made but none of the existing work could directly be transferred to the Arctic module design.

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\*Portable Observation Laboratories for Arctic Research

The proposed polar room module system consists of 8 x 8 x 8 ft. room modules which have side walls but no end walls. The room modules can be closed at the ends with separate 8 x 8 ft. end panels.

To keep the room modules lightweight the side walls, the floor and the roof are made as a continuous sandwich panel consisting of polyurethane foam with aluminum skin inside and outside. The end panels are made in two versions: a fireproof end panel made of steel, asbestos and fiberglass, and a lightweight end panel made of wood, polyurethane foam and aluminum. Through a considerate combination of room modules and fireproof end panels the total shelter will have fire walls separating the various zones of use. Doors and windows can be placed both in the side walls of the modules and in the end panels.

### III. PROGRAM ACTIVITY FORECAST

As mentioned earlier, the Arctic Technology Program has stimulated a considerable scientific interest at the University of Washington in polar operational problems. As solutions to these problems are formulated, they are systematically reviewed by the Arctic Technology Advisory Committee and subsequently may be prepared as proposals to ARPA and other Federal agencies. During the coming year the major activity in the program will relate to the completion of the UARS system; however several of the more promising technical concepts referred to above will also be described briefly in this section in order that the reader may be aware of the direction of our technical thought in Arctic research.

#### A. UARS System Fabrication, Test and Deployment

This portion of the UARS system development will commence as soon as the design has been completed (June 1971). Present plans are to use the following Arctic working season (March-June 1972) for field trials and initial Arctic deployment.

Fabrication of two submersibles is planned in order to have adequate component back-up and testing flexibility. Upon completion of the test and trial period in the deep polar pack region, it is planned to deploy the UARS system to the Marginal Ice Zone (MIZ) in the Chukchi Sea (August--September 1972) for testing in the shallow, acoustically anomalous waters of the Arctic continental shelf. There the vehicle will be launched and recovered from a platform located in the broken ice field and the tracking system will be positioned in a different geometry to enhance UARS control.

It is presently understood that two Arctic projects sponsored by the Government are planned for the spring and summer of 1972. The first is a phase of the internationally recognized AIDJEX scientific program which will be conducted on the pack ice, or possibly near Ice Island T-3, and the second covers ARPA-sponsored work to be undertaken by the Arctic Submarine Laboratory in the Western Marginal Ice Zone. Each of these programs could clearly provide convenient logistic support for the initial UARS arctic trials.

In return, the submersible would be able to provide valuable scientific data to supplement the measurements taken in AIDJEX and the MIZ program. Close coordination has been maintained with both the AIDJEX and MIZ program offices. As a result, many of the design features of UARS and its instrumentation will expressly satisfy data collection requirements for these programs. In the MIZ, UARS may prove to be the only effective means available for studying and mapping the horizontal distribution of salinity and temperature variations. It is planned to make the UARS system available to support that MIZ program as soon as Arctic trials have been completed.

There are several immediate applications for UARS which support the Arctic Submarine Laboratory and also the Navy ASW program. Under the polar ice pack there is very little known about the character of acoustic propagation in the vicinity of the ice surface. The situation is further complicated by the shallow bottom found in much of the MIZ. To understand the absorption, scattering and refraction qualities of this environment it will be necessary to perform a number of experiments in which UARS could have a unique role. First, its profiling instrumentation could be used for mapping the under-ice topography (scattering surface) of the experimental site. Next, it would serve as a mobile acoustic projector traveling much closer to the ice surface than the skipper of any present submarine would dare, and finally its profiling receiver could be easily adapted to provide very low angle-of-incidence backscatter data from a moving source. Simultaneously it would record salinity and temperature thus giving the oceanographic data needed for correlation, analysis and operationally useful interpretation.

The Marginal Ice Zone is considered by many to be the most important region of the Arctic from the standpoint of strategic defense. Since it includes areas of shallow water, changing ice fields, strong currents and highly variable salinity and temperature conditions, it presents both a formidable ASW environment and an area of high potential threat from offensive ballistic missile submarines. As the Arctic receives more recognition in terms of submarine defensive requirements, the UARS system is expected to play an increasingly more significant part not only in research but as a test-bed for future weapon system development. Another useful application would be to design UARS instrumentation and transducers to simulate full scale submarine acoustic systems. The submersible could thus quickly become a platform to study, at low risk, the operational behavior of (1) submarine ice avoidance sonar, (2) Arctic torpedo homing subsystems, (3) reverberation characteristics compared to target signatures, and (4) decoy development and other tactical requirements. Other UARS configurations could be employed to gather a wider selection of fundamental data throughout the Arctic, typically, measuring

- (1) Acoustic backscatter from the ice underside using directional transducers to vary the angle of incidence.

- (2) Radiant flux through the ice for thickness prediction.
- (3) Horizontal temperature and salinity behavior in the vicinity of leads to permit the understanding of thermal advection processes (important for sonar bearing refraction analysis in regions of dilating ice pack).

These and other applications have been suggested by DOD scientists and program managers, and by participants at an Arctic Technology Program Review and Planning Meeting held at the Applied Physics Laboratory on 8-9 December 1970.

UARS is readily adaptable to new instrumentation, hull configurations, and missions. For example, the present vehicle has 200 lb. of unused payload which could be converted to new instrumentation. Several ports are provided for future installations and the removable nose plate is readily adaptable for mounting new sensors.

The speed of the vehicle could also be increased to provide greater depth control stability and maneuverability--both desirable features when operating close to the ice. Increased endurance can be obtained by adding a second battery section. (An increase of 2 ft. in vehicle length would double the battery capacity without appreciably increasing body drag or affecting control characteristics.)

The UARS system is not limited to small area coverage but can make traverses of many miles by using the homing unit for primary guidance. In this mode, the submersible homing unit would be locked onto successive beacons placed along the desired track. One beacon at a time would be activated, and progressive sequencing would be accomplished by using range measurements between the tracking projector on the UARS and hydrophones installed with each beacon. The number of beacons required for a given track length would be a function of the beacon source level and propagation path characteristics. In the central Arctic an inter-beacon spacing of several miles can be achieved. Similarly, the UARS tracking system need not be constrained to employment on ice floes but could be mounted on vehicles capable of operating over ice, or on platforms in open Arctic waters.

#### B. Polar Ice Pack Utility Vehicle

For many years scientists participating in Arctic research projects have expressed frustration over the inability of available vehicles to accomplish short journeys over the ice pack with economy, safety and reliability. This is due in some measure to the extremes of the Arctic environment--the low temperature, winds and jagged surface contours resulting from pressures in the ice pack. The performance specifications for currently available Arctic transportation vehicles were never intended to meet the requirements of the field scientist and, consequently are poorly suited for routine Arctic work.

A fresh approach to the design of a polar ice pack transportation vehicle is clearly needed. The most important consideration for such a vehicle should be absolute reliability between points on the ice pack. Adopting new performance specifications will be essential in achieving this goal. Some changes might include:

1. Reduced speed and increased endurance for reduced complexity and more efficient pulling capability for trailers. (High speeds are neither necessary nor safe on pack ice.)
2. Amphibious capability, so that the vehicle can float if it should break through thin ice, or can traverse small areas of open water and return safely to the ice pack.
3. Inexpensive construction, easy servicing and long parts life between overhauls.

The Department of Mechanical Engineering is currently examining the fundamental needs for surface transportation in support of Arctic research. The summary of their work will include a reasonable set of performance specifications for a vehicle to satisfy those needs.

#### C. Short Range Secure Acoustic Data Transmission

Among the many unsolved problems related to operation and data collection in the Arctic Ocean the retrieval of information from sensor systems emplaced beneath the ice cover is one of the most significant both from a military and scientific standpoint. In many important polar regions the ice cannot be used to support instrumentation for long-term measurements because it is either moving, melting or breaking up. Attempts have been made to place and retrieve bottom-mounted sensor packages under these conditions but to date there have been no successful recoveries. Either the equipment cannot be relocated or ice movement precludes ship operations in the areas of interest. The resultant loss of valuable hardware, the high cost of ship time spent in fruitless searching and the delays to ongoing research projects caused by a lack of essential field data are serious handicaps to our national Arctic program.

This problem was intensively discussed among members of the Arctic Technology Advisory Committee. It was concluded that the best solution, and one which is feasible within the present state-of-the-art, would be to develop a high frequency acoustic data link to transmit information between a permanently moored data buoy and an appropriate receiver (surface or submarine). A data link of this type was developed specifically for the tracking and control of the UARS, and it could be adapted to solve the under ice buoy problem with relative ease. Therefore, consideration is now being given at the Applied Physics Laboratory to the design, fabrication and testing of an acoustic data transmission system.

Conceptually, sensor signals gathered over an extended period of time (6 mo. - 1 yr.) would be processed and stored internally on magnetic tape in the buoy. At some time prior to expiration of the tape storage capacity a receiving unit would be brought within range (approx. 1 mi.) of the buoy. This could be done using a helicopter or light plane at the surface of a submarine beneath the ice. Upon interrogation, the buoy would acoustically transmit its stored data at a high rate to the receiver. A pulse- or frequency-shift-keyed code similar to that successfully used in UARS would be adopted for transmission since it is tailored to reject false or anomalous signals that can occur beneath the ice. The high frequency, coded signals from the buoy transmitter are inherently quite secure because of rapid attenuation. However, they can be even more closely controlled by using a very narrow beam acoustic projector in the transmitter and receiver. The system would be useful with any sensor package (surveillance, oceanographic, geophysical, etc.) that was to be located beneath the ice. It could function satisfactorily in shallow or deep water; could announce its presence with a beacon or remain silent until interrogated; and could be addressed from any convenient, reasonably close location. The buoy itself would be considered expendable, but could have a programmed life of several years using relatively inexpensive power sources.

#### **D. Electromagnetic Detection of Targets on Pack Ice--Enhancement and Suppression**

The problem of detecting foreign objects in a polar ice field has become of increasing concern to many offices of the federal government. In the Navy this takes the form of an ASW requirement where it is important to be able to discriminate between normal radar clutter from ice and a submarine antenna or superstructure. In sea-air rescue work the Coast Guard and Air Force must be capable of quickly locating a disabled aircraft among the pressure ridges and leads of the ice pack; and for NOAA and NSF, good EM detection will be important in locating accurately the future scientific data buoys that will be emplaced in the moving ice cover to record environmental data.

In recognition of this need in the Arctic, the Division of Marine Resources, the Department of Electrical Engineering and the Applied Physics Laboratory are preparing a plan to investigate the magnitude of this detection problem from a technological standpoint and to develop new techniques (signal processing, propagation pattern modification, etc.) to increase the probability and reliability of all weather target acquisition. The frequency range from RF to IR would be employed in this work so that adequate sensor correlation can be provided to assure an acceptably low rate of false targets.

The investigators could simultaneously address the counterpart to detection at the ice surface--concealment. This would include a careful study of all known techniques for radiation suppression. Different absorbent structural materials, insulating coatings, target shapes, etc. would be



analyzed and tested. Target strength measurements for many target aspects, and in a wide range of ice surface conditions would be conducted using the equipment developed for detection enhancement. The final product of research of this type would be a working prototype of an airborne instrumentation suite together with a set of specifications for government procurement; and a manual of materials and techniques to be used for EM cross-section reduction or concealment on the polar pack.

#### E. Acoustic Probing of the Arctic Atmospheric Boundary Layer

The technique of obtaining information about the atmospheric boundary layer by means of acoustic sounders or SONAR has been developed in the last few years and appears to be very promising for the study of the boundary layer. It is felt that this technique may be particularly useful in the Arctic for the following reasons:

1. Sound absorption is relatively low at low temperatures because the moisture content is small. Consequently higher frequencies may be used giving better resolution of the received signal.
2. The Arctic pack ice forms a large relatively uniform surface over which the boundary layer may obtain a quasi steady state condition, which facilitates the testing of theoretical models.
3. Over long periods the boundary layer is stable. The structure of the stable boundary layer is still poorly understood. Fairly complete profiles may provide significant new information for use in predicting significant meteorological phenomena.
4. In the stable boundary layer transitions from laminar to turbulent flow and vice versa occur. Consequently turbulent layers may be found in a predominantly laminar flow. It is suggested that such turbulent layers are very similar in structure and formation to the patches of clear air turbulence found near the tropopause in temperate latitudes. Therefore intensive study of the stable Arctic boundary may yield valuable insight into the phenomenon of clear air turbulence. It is clear that acoustic probing of the boundary layer with a rather simple (and inexpensive) sonar is much less expensive and more convenient than the remote sensing of clear air turbulence near the troposphere with sophisticated high resolution radar.

The objective of research in this area would be to obtain good quality wind information throughout the atmospheric boundary layer to a height of about 1 km. To do this it would be necessary to develop an acoustic echo sounding technique which provides quantitative velocity profiles, and, subsequently, to carry out a thorough analysis of all atmospheric data which is obtained. The necessary theoretical and technical experience for this exists in the Applied Physics Laboratory and the Department of Atmospheric Science.

#### F. Acoustic Determination of the Near Surface Structure of Permafrost and Sea Ice

The subsurface structural analysis of permafrost is presently a very difficult but necessary task. This is particularly applicable to the problems associated with rapid Arctic tactical troop deployment and to the building of structures, such as oil pipelines, where the subsurface must be non-destructively surveyed. Furthermore, the ability to characterize permafrost in 3-dimensions would be of great value for geomorphological studies. Unfortunately, one of the most useful geological tools, seismology, is not applicable to this problem because the acoustic "time of flight" to the depths of interest (the first 50 feet) is so short that the desired information is lost in the explosion reverberation. Boundaries in the medium may still be located by using acoustic echo techniques involving short, well defined source pulses of the proper frequency.

The Applied Physics Laboratory could perform the experiments necessary to make a reasonable estimate of the feasibility of using pulse echo techniques to measure the subsurface structure of permafrost. This would require instrumenting both ideal and undisturbed permafrost samples in which the physical constituents are to be analyzed and which contain interfaces. The samples could be furnished by the Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire or the University of Alaska at Fairbanks, Alaska. It is recognized that the results of these tests might not resemble those from in-situ conditions; therefore, field tests would be carried out to verify the results after successful laboratory feasibility demonstration. Design criteria for instrumentation would then be prepared.

#### IV. CONCLUSION

In view of the significance of new approaches and equipment which the Arctic Technology Program promises to offer the scientific community, we believe this first year of activity has been both encouraging and productive. The UARS system has been well received generally and has stirred international interest in its potential hydrographic applications in the northern Canadian archipelago. Planning for the spring of 1973 now includes UARS operation in Greely Sound, Ellesmere Island.

The program clearly demonstrates that ARPA's interest in developing advanced techniques to overcome the classical problem areas of Arctic research has 1) stimulated new interest in the polar regions, 2) raised the level of the talent pool that is available for future use and 3) set the stage for a quantum jump in the collection of useful Arctic data. Within the program we have also been able to establish a forum where the scientific and technical disciplines can jointly contribute new approaches to the methodology of cold regions research.





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# **Unmanned Arctic Research Submersible System Development Report, Phase I**

by  
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**Applied Physics Laboratory  
University of Washington**

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## 1. INTRODUCTION

As part of the ARPA-sponsored Arctic Technology Program at the University of Washington, the Applied Physics Laboratory has been engaged in the development of an unmanned, untethered submersible system for research work under arctic ice and in the marginal ice zone. This report summarizes the results of the first year of a two-year design, development, construction and deployment program. In the Arctic Ocean much of the phenomena of operational importance is close to the sea-ice interface and is directly related to the presence of the ice canopy. The Unmanned Arctic Research Submersible (UARS) system is being developed to allow the systematic exploration of this region. An artist's concept of the vehicle in operation, performing an under-ice profiling mission is shown in Figure 1.1. The UARS vehicle and support equipment represents an extension of a highly developed system for open ocean research which was perfected by APL. This system, known as the Self-Propelled Underwater Research Vehicle (SPURV), is now in its fourth generation and is specifically configured to operate in the deep ocean (to 3500 meters) and be recovered from the open sea surface. The arctic vehicle, on the other hand, must perform in the more complex acoustic environment of shallow, ice-covered seas with a precision that will allow it to be launched and recovered through a small hole in the ice.

The first year of effort has been devoted to system design and subsystem component development. Fabrication and testing will be carried out during the second year. UARS will initially make measurements of the roughness and contour of the ice underside. Somewhat later it will be used as a platform from which to study horizontal and vertical variations in temperature and salinity, and the acoustic reverberation from the ice. This kind of information is extremely valuable for arctic submarine operations. One goal of the UARS system development is to provide a reliable and reasonably economical means of routinely gathering important arctic oceanographic and acoustic data. However, this vehicle will be capable of accomplishing tasks of naval importance which range far beyond the collection of physical oceanographic data.

## 2. DEVELOPMENT PROGRAM

### 2.1 PHASE I UARS SYSTEM DEVELOPMENT, AND BRIEF SYSTEM DESCRIPTION

The first phase of the UARS program has been devoted to design and component development for the full system. The objective is to provide a technological capability for conducting under-ice research with unmanned, untethered vehicles. No such capability now exists. What research is accomplished from mobile platforms must be done from nuclear submarines which, because of high operational priorities, are seldom available. When submarines are used they must operate at a "safe" distance below the ice which is so far removed from the region of greatest oceanographic and acoustic variation (near the ice interface) that direct measurements are precluded. The UARS program goal is to provide a more effective means to accomplish these research tasks.

The UARS system design consists fundamentally of a torpedo-size vehicle, a scientific instrumentation suite and a supporting subsystem for launching,



Figure 1.1. Unmanned Arctic Research Submersible (UARS) Performing an Under-Ice Profiling Mission

tracking, command, and recovery. These are described in detail in Sections 4 and 5; however, a brief overview of the component functions follows.

UARS is a compact vehicle which weighs approximately 1000 lb, has a length of approximately 10 ft and a diameter of 19 in. Oceanographic measurements could be taken at speeds exceeding 6 knots but ice surface profiling will be done at 3 knots. The main batteries will supply up to 10 hours of run time. The principal acoustic components carried by the vehicle are for communication, tracking, homing and collision avoidance. The latter is necessary because of potential massive ice keels that could project into the path of the oncoming submersible. The initial instrumentation suite of UARS will also feature acoustic sensors incorporated into an ice profiler that are capable of measuring surface elevations to a differential accuracy of 0.25 ft.

For launching, the vehicle will be lowered by a special sling through a 4 x 12 ft hole in the ice and released from a horizontal position at a depth of approximately 50 ft. Special procedures have been developed to facilitate making the access hole in the ice.

Tracking elements in the system are: (1) an array of three or more RF-telemetering hydrophones arranged in a pattern which defines the experiment or survey area; (2) two baseline acoustic projectors which are normally located within the survey area and provide coordinate reference axes; (3) an acoustic source aboard UARS; and (4) the timing units, data processors and power supply which provide the basis for interpreting the acoustic signals and making rapid position calculations. The hydrophones and baseline projectors are designed as free-floating buoys, but can be frozen in place, weather permitting. At the power levels and frequencies used each hydrophone will have an effective tracking range of 9000 ft. The command/communication components will utilize the same acoustic frequency as the tracking elements. Sixteen command functions are available for controlling UARS.

For retrieval, a snaring net containing a homing beacon will be lowered through the ice hole to the operating depth of the submersible and UARS will be commanded to seek the homing signal. Internally programmed logic, an inertial and depth-sensing guidance system, and the command/tracking receivers provide UARS with retrieval redundancy. However, in the event of massive power interruption or other catastrophic failure, the submersible is positively buoyant and will rise to the undersurface of the ice. It then automatically lowers an acoustic beacon to aid an over-the-ice search party. A full array of recovery tools will be available for such an operation.

To date, all subsystems (except those associated with process controller hardware to be procured in Phase II) have been designed and tested in the Laboratory. Some have undergone tests in local waters and all acoustic systems have been tested in the arctic under-ice environment.

## 2.2 PHASE II FABRICATION, TEST AND DEPLOYMENT

Phase II of the UARS system development will make use of the arctic working season of March-May 1972 for field development work and initial deployment. Components with long requisition lead times will be purchased immediately after funding is available so that local submersible trials can be completed before mounting the arctic activities.

Two submersibles will be fabricated in order to have adequate backup components and testing flexibility. The initial UARS deployment site will be chosen early in Phase II and will be a deep water, central arctic site at which logistic support for research programs is available. Two such sites are under consideration: one is Fletcher's Ice Island, T-3, a permanent research camp; the other is the AIDJEX (Arctic Ice Dynamics Joint Experiment) camp site which is expected to be established in the western Beaufort Sea during March-April 1972. Since the initial deployment mission is primarily aimed at completing the system development, the assured logistic support and camp permanency of T-3 are particularly desirable. At some later date, when the AIDJEX year-around camp is established, it is anticipated that research with the UARS system will complement that experiment.

The principal scientific result sought in Phase II is a representative sample of high resolution under-ice profile data which will be correlatable with surface topography measurements -- the latter to be made along UARS traverses by a ground truth party using conventional surveying techniques. A complementary, cooperative experiment is to be established to this end.

## 3. UARS SYSTEM APPLICATIONS AND GROWTH CAPABILITY

### 3.1 APPLICATIONS

Following initial arctic deployment of the submersible in Phase II, there are several immediate applications for UARS which support transportation, defense, and scientific programs.

Studies of under-ice topography have an important bearing on establishing feasibility of submarine transport operations. Commercial feasibility depends upon navigational and ice avoidance sonar systems which permit reasonably high speed operation in close proximity to the ice and bottom in the extensive marginal sea areas of the Arctic. UARS can serve as a mobile acoustic projector test platform and the test data can be correlated with the under-ice topography measured by the profiler. Similar measurements can assist in the establishment of the differences in ice reverberation and target signatures for both search sonar and submarine defensive systems.

The refraction of acoustic beams by horizontal temperature-salinity variations can be studied from both theoretical and experimental viewpoints by combining elements of the UARS instrumentation system. The temperature-salinity investigations that relate to horizontal refraction of acoustic rays also provide an element in the study of thermal advection processes, particularly those associated with leads. Information on these processes is vitally important to the development of reliable ice forecasting. In this application, the UARS profiling and positioning system outputs provide a means for lead identification and determination of their dimensions.

In all of the above applications, the ice profile data obtained will relate to questions and answers with respect to ice movement due to currents, establishment of diffusion limits of under-ice oil spills and recovery procedures, long range multi-surface bounce acoustic transmission problems, and sea ice thickness statistics.

### 3.2 GROWTH CAPABILITY

UARS has been designed for ready adaptability to new instrumentation, hull configurations, and missions. For example, the present vehicle has 200 pounds of unused payload, much of which could be replaced with new instrumentation -- assuming that most instruments could be located appropriately to maintain the required vehicle trim conditions. Several ports are provided for future instrumentation and the removable nose plate is readily adaptable for mounting new sensors.

The speed of the vehicle could also be increased to provide greater depth control stability and maneuverability -- both desirable features when operating close to the ice. Increased endurance can be obtained by adding a second battery section. This section would increase the vehicle length by 2 ft and double the battery capacity without appreciably increasing body drag or affecting control characteristics.

Present plans are to include salinity and temperature sensors as part of the initial instrumentation suite. Two internal data channels have been reserved for recording these sensor outputs.

The UARS system is not limited to small area coverage but can make traverses of many miles by using the homing unit for primary guidance. In this mode, the submersible homing unit would be locked onto successive beacons placed along the desired track. One beacon at a time would be activated, and progressive sequencing would be accomplished by using range measurements between the tracking projector on the UARS and hydrophones installed with each beacon. The number of beacons required for a given track length would be a function of the beacon source level and propagation path characteristics. In the central Arctic an inter-beacon spacing of several miles can be achieved. Similarly, the UARS tracking system (described in Section 4.3) need not be constrained to employment on ice floes. The tracking elements can be mounted on vehicles capable of operating over ice, for example, or on platforms in open arctic waters.

## 4. THE OVERALL SYSTEM

### 4.1 GENERAL

The UARS system consists of two major elements -- an unmanned submersible which serves as a mobile instrument carrier, and a remote tracking, guidance, and recovery system. The design maximum operating depth of the submersible has been established as 1500 ft. The initial design provides for a nominal velocity of 3 knots.

The maximum operating depth of 1500 ft was selected because it is consistent with envisioned experimental programs and because proven technology for shell and component design is available for that depth. The design velocity of 3 knots was selected because a control system designed for this velocity could, with minor changes, be employed for higher velocities; whereas the reverse does not necessarily follow. This velocity also is compatible with initial experiment objectives.

Ten hours is thought to be a reasonable length of run time, considering both the available data recording capacity and human factors. A separate reserve energy source will provide an additional 2 hours operation at full power for emergency situations.

The nominal distance traveled by UARS in a 10-hour run will be 30 nautical miles. Simulation studies have indicated that for experiments where larger traverses are required, a second battery section can be added without appreciably altering the control system performance and only modestly reducing the velocity. This would approximately double the endurance and range of the vehicle.

The energy requirements of UARS will be satisfied with silver-zinc secondary batteries. A 14-inch diameter, 24-inch pitch propeller powered by a 1/4 hp, pressure equalized (flooded) dc motor will be used for propulsion.

The hull diameter is 19 inches, a dimension for which hull technology is well established. The weight and volume requirements for all subsystem components (propulsion, energy source, control, field instrumentation, data recording, etc.) and their placement within the vehicle resulted in a final submersible length of ~118 inches and a displacement of 15.5 cubic feet or approximately 1000 lb. The design provides a buoyancy reserve of 200 lb for additional instrumentation.

The view of UARS in Figure 4.1 shows the location of the components that are described in the following sections. The submersible itself is described in greater detail in Section 5.

#### 4.2 UARS PROFILING SYSTEM

An immediate objective of the first phase of the UARS program was the development of a system to accurately profile the ice underside. This will be accomplished by measuring the elevation of the ice surface above the vehicle at regular intervals. Our performance goal is to establish these elevations to a differential accuracy of 0.25 ft and to identify the corresponding plan view coordinates (derived from tracking information) to a repeatable accuracy of 1 ft and a differential accuracy of 0.5 ft. The data rate will allow the elevation measurements to be made at about 1-ft intervals in the direction of UARS motion.

The profiler receiving transducer is a spherical, two-component acoustic lens, with 15 transducers located in the focal surface. Figure 4.2 shows the



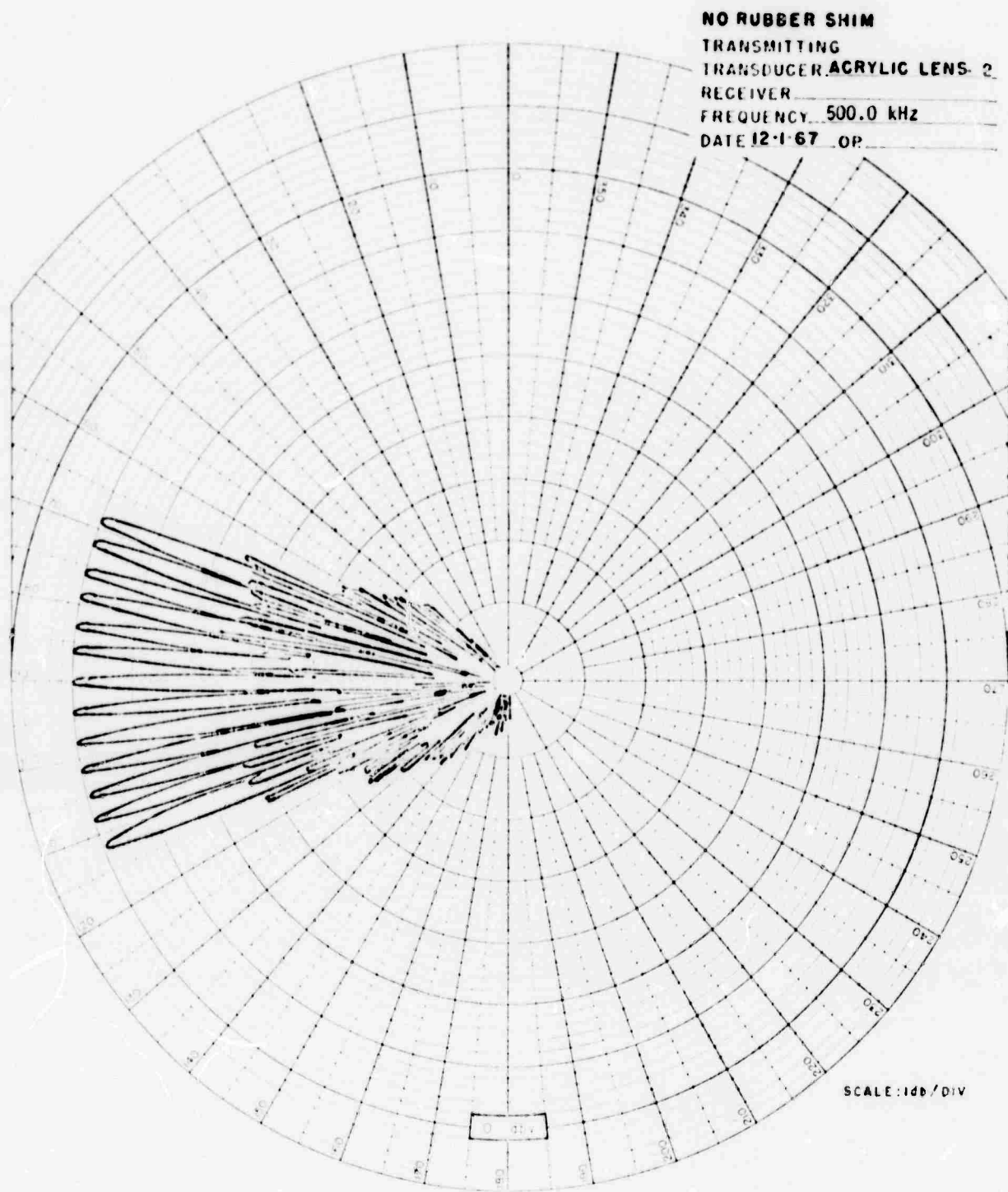


Figure 4.2. Directivity Pattern of Multiple-Beam  
Transducer-Lens System



resulting directivity patterns of the individual transducers. The individual beam width or the half power points ( $-3$  dB) are about  $1^\circ$  wide at the 500 kHz operating frequency. In operation, the profile transmitter transducer, which is located just forward of the multibeam receiver transducer (see Figure 4.1), is pulsed and the reflected signal in the direction of the receiving beams is detected. The overall transit time provides a measurement of slant range. The "fan" of multiple beams is oriented perpendicular to the direction of motion of the vehicle. The capacity of the recorder limits the useful reception to any three of these beams; selection of the appropriate three can be made in the field. Normally, the submersible will operate about 50 to 60 ft below the ice. At that depth the insonified area associated with the reflected signal is about 1 square foot. At a vehicle speed of 3 knots and the five data sets per second recording rate, this provides essentially continuous surface sampling.

The geometry of the measurement is shown in Figure 4.3. The elevations  $z_{b1}$ ,  $z_{b2}$ , ... represent successive measurements of ice elevation from lens

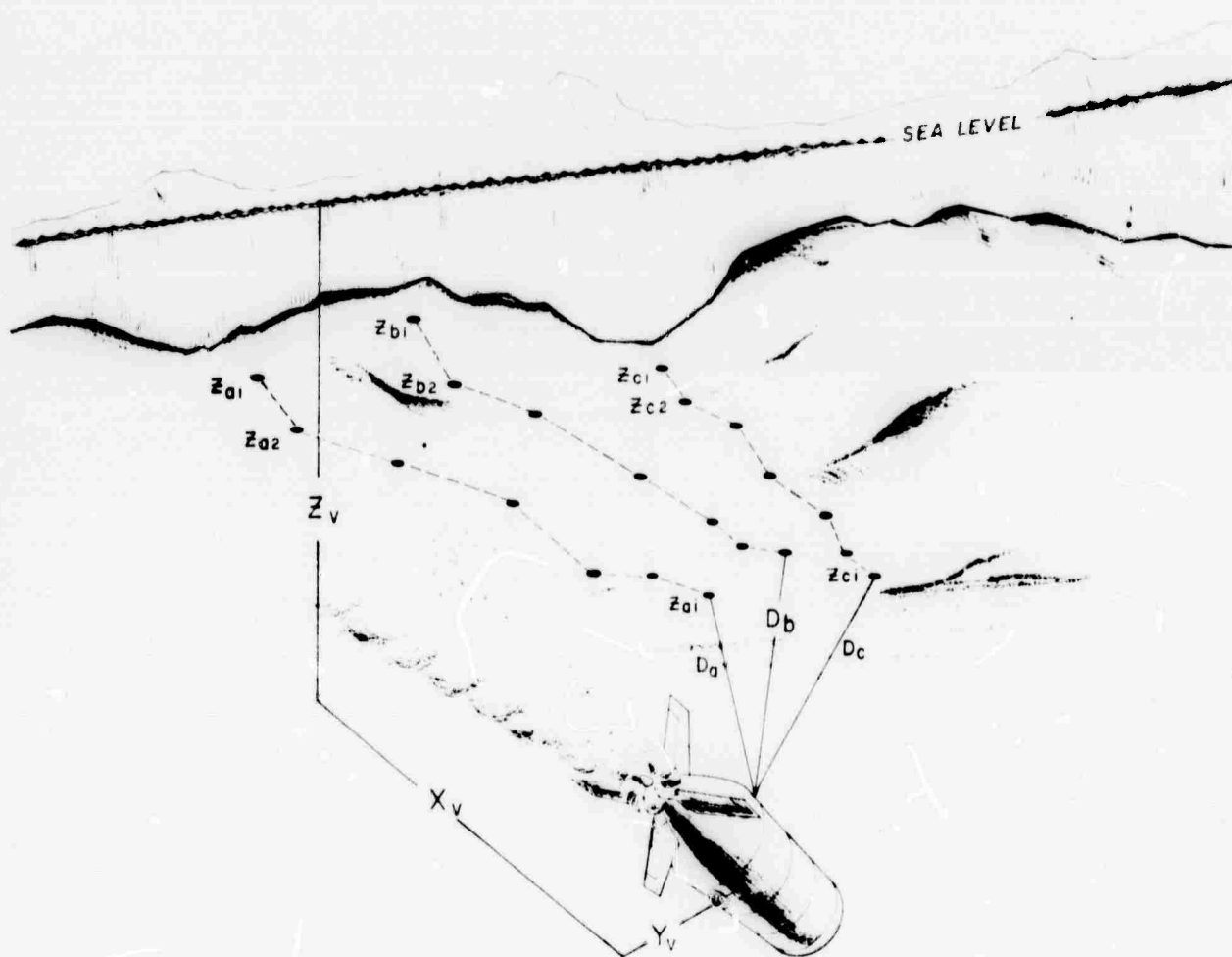


Figure 4.3. Measurement Geometry of UARS Profiling System

transducer element b.  $z_b$  is determined by combining the depth of the vehicle (sensed by an internal pressure device) with the slant range  $D_b$ , and correcting the measurement for vehicle roll, pitch and yaw. In order to determine corresponding values of  $X_b$  and  $Y_b$ , corrections must also be applied to the X-Y coordinates of the vehicle tracking transducer to account for beam angle, vehicle roll, pitch and direction of advance. The UARS data system records roll, pitch,  $D_a$ ,  $D_b$ ,  $D_c$ , depth, and time for later correlation with synchronized externally sensed and recorded X-Y coordinates of the vehicle. All data recorded within the vehicle is stored in binary form. The resolution of  $z_{b1}$ ,  $z_{b2}$ , ... is approximately 0.5 ft, based upon combined quantizing limits.

#### 4.5 TRACKING, COMMAND AND RELATED INTERACTING SYSTEMS

##### 4.5.1 OPERATIONAL REQUIREMENTS

The UARS system has been designed to satisfy the following special operational constraints imposed by the Arctic:

- (1) The vehicle must be launched and recovered from a hole in the ice.
- (2) It must operate in close proximity to the ice undersurface.
- (3) It must have an accurate and reliable tracking system to enable the data to be spatially correlated and to prevent loss beneath the ice canopy.
- (4) It must accept control commands from the experiment controller so that anomalies in the data can be investigated more thoroughly as they occur.
- (5) Real-time data transmission to the surface command console must be provided.
- (6) The vehicle must be recoverable with a high degree of reliability and minimum personnel risk.
- (7) Immediate field reduction of the data from a run must be possible to assist in planning subsequent measurements and to permit thorough investigation of anomalous results.

The UARS system design innovations which were developed to meet these special considerations are detailed below.

##### 4.5.2 LAUNCHING, RECOVERY AND OBSTACLE AVOIDANCE

The submersible is designed for launch and recovery through a rectangular hole (about 4 x 12 ft) cut in the ice. After the initial instructions are set into the vehicle and its internal systems are operating properly, it is lowered into the water to a depth of 30 or 40 ft below the ice, using a launching sling. Acoustic communication and tracking signals are then established. The propulsion motor is started and the launching sling released.

Since UARS normally carries a slight positive buoyancy, it will rise slowly as it gains forward velocity until the speed is sufficient to bring it under full control of the depth keeping system. Thereafter, it will follow a preset depth program.

Recovery of the vehicle is illustrated in Figure 4.4. The basic technique is to lure the vehicle back to the recovery hole by means of an acoustic homing system installed in the vehicle. This system responds to a particular signal that is transmitted from a homing beacon centered in the capture net. The final phase of homing is conducted at a preset depth so that it is necessary to steer in azimuth only, the net being set at the terminal homing depth. A capture probe mounted in the nose of UARS is firmly meshed with the net upon contact. The motor is then commanded "off", the net and vehicle are raised to the surface, and UARS is hoisted clear of the water.

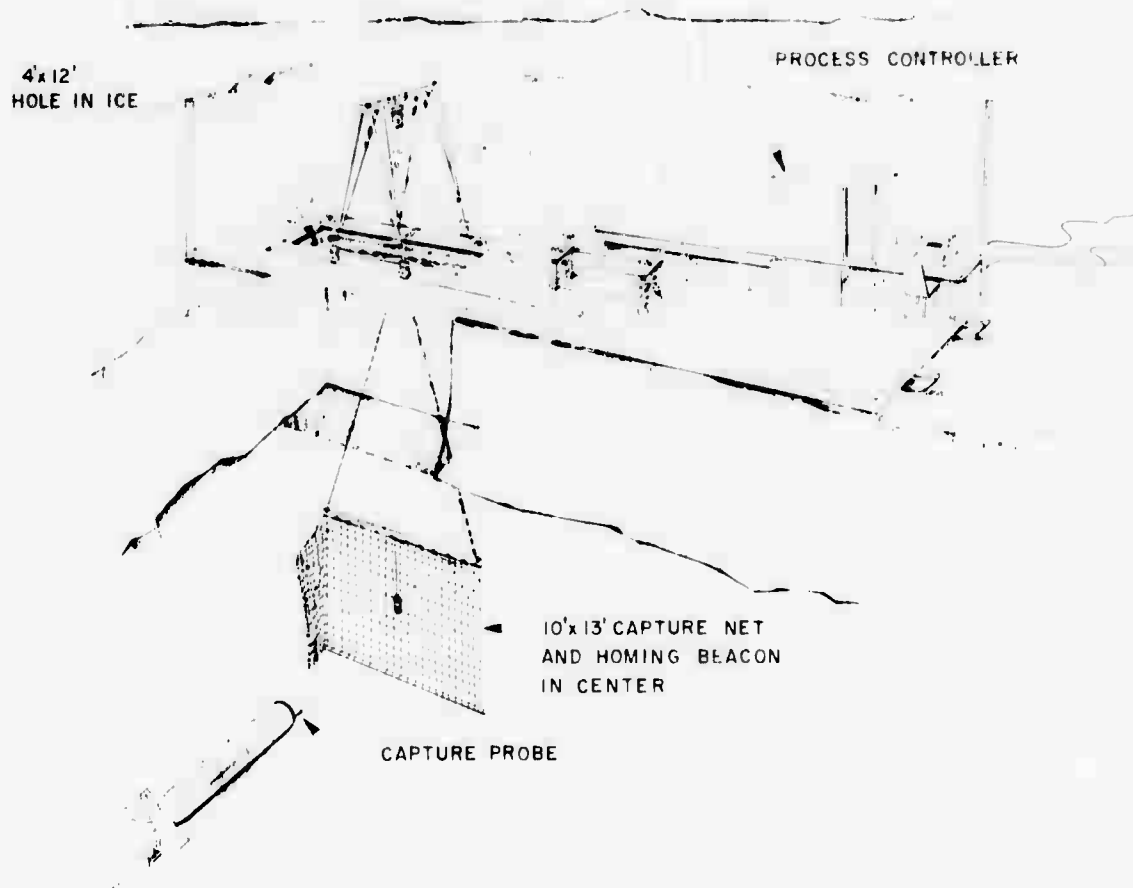


Figure 4.4. UARS Recovery System

The homing system employs two closely spaced hydrophones whose outputs are filtered for response at the beacon frequency and phase compared to generate azimuthal steering orders. Reflection of the beacon signal from the ice undersurface can cause ambiguous phase relationships so the homing system includes an interlocking set of logic which must be satisfied in order to cause homing on the direct path pulse only. A simplified flow diagram which describes the logic chain is shown in Figure 4.5. In addition to the bearing

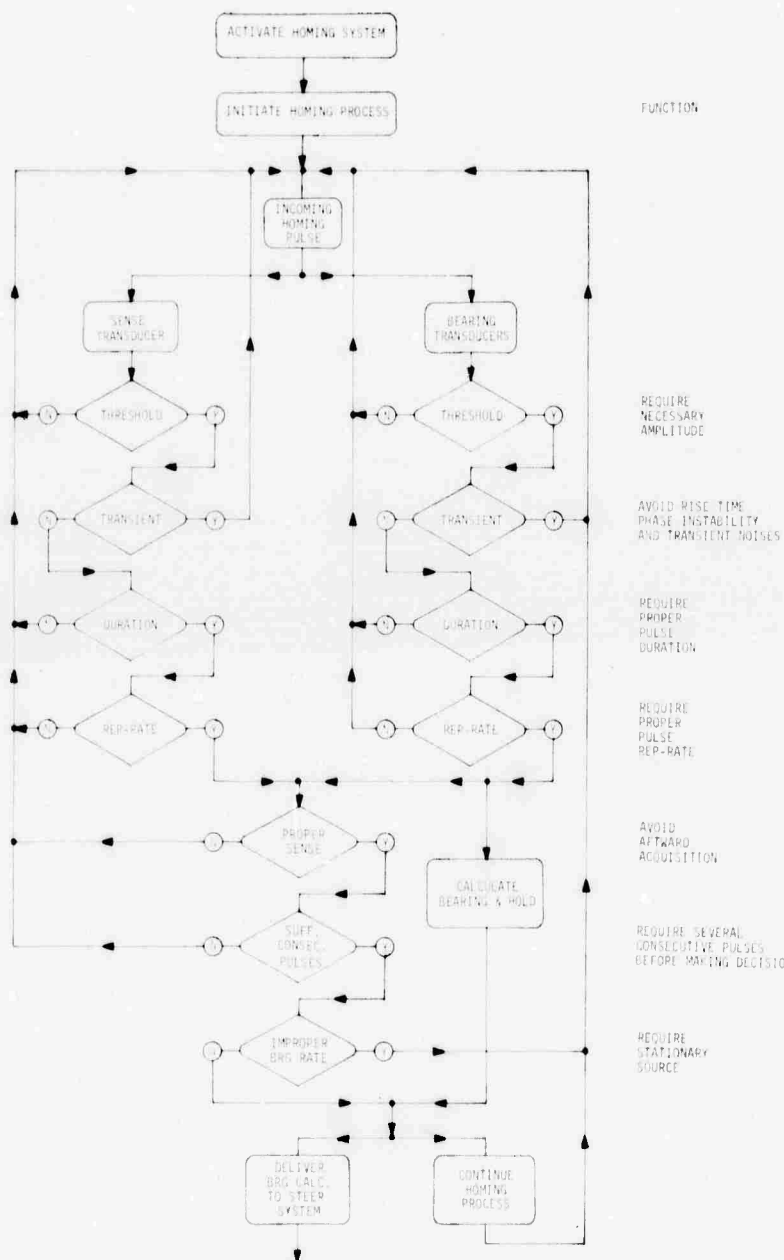


Figure 4.5. Simplified Flow Diagram of Homing Receiver for UARS

measuring transducers, a sensing hydrophone mounted on the aft cylindrical section of the vehicle is employed. The logic chain requires that the pulse sensed at the steering hydrophones precede the pulse detected at the sensing hydrophone by a fixed time (0.8 msec) which ensures that the detected signal is in the forward sector,  $\pm 45^\circ$  with respect to the vehicle axis. The logic rejects any rate of change of the detected phase imbalance between the steering hydrophones which exceeds the maximum valid vehicle bearing rates with respect to the fixed target beacon. Other requirements ensure that the detected signal has the character of the transmitted signal. These features are necessary to overcome interference effects noted in tests of the basic phase detector system during under-ice tests in the arctic. Previous tests in Puget Sound during the winter, when the vertical sound velocity profile allowed long direct path acoustic propagation, utilized the same acoustic system but with a much simpler logic. Signals in excess of steering threshold requirements were obtained at ranges greater than 3 miles when using an 80 dB CW beacon (28 kHz). During the arctic tests discussed in Section 6.3.3 an operating range of 2 miles was achieved with the same equipment. The difference in range is almost exactly accounted for by greater absorption losses associated with the lower water temperatures in the arctic tests.

To avoid collision with deep pressure ridge keels, the vehicle is equipped with an obstacle avoidance sonar. This system operates at a frequency of 360 kHz, employing a 200  $\mu$ sec pulse which is about 1 ft long. Pulse length broadening, an expected characteristic of the return from the ridge keels, will be used for pulse validation. This will allow easy rejection of fish echoes. The high attenuation at this frequency allows a high pulse repetition rate (five pulses per second) so that obstacle avoidance logic can be based on receipt of multiple valid returns. The sonar beam is axially directed and is of sufficient width to encompass normal pitch oscillations and trim conditions of UARS. When an obstacle is detected, the vehicle dives to a deeper preprogrammed depth. After the obstacle is passed, the vehicle can be commanded to return to the original depth if desired.

#### 4.3.3 ACOUSTIC TRACKING

A plan view of a typical tracking area arrangement is shown in Figure 4.6. Four hydrophones (labeled H in the figure) will be installed through holes in the ice in a square arrangement 6000 ft on a side. Two baseline transducers (labeled T) would be located about 2000 ft apart in the center of the square. The origin of the tracking coordinate system and the direction of the coordinate axes are determined arbitrarily by the location of the baseline transducers. The general geometry of the tracking and command/communication system arrangement is shown in Figure 4.7. At fixed time intervals of 2 seconds, an acoustic pulse is transmitted from UARS. At the same time, a pulse is transmitted from one baseline transducer. The pulses transmitted by the baseline transducer and the submersible are received at hydrophones and relayed by radio to the control building where they are entered

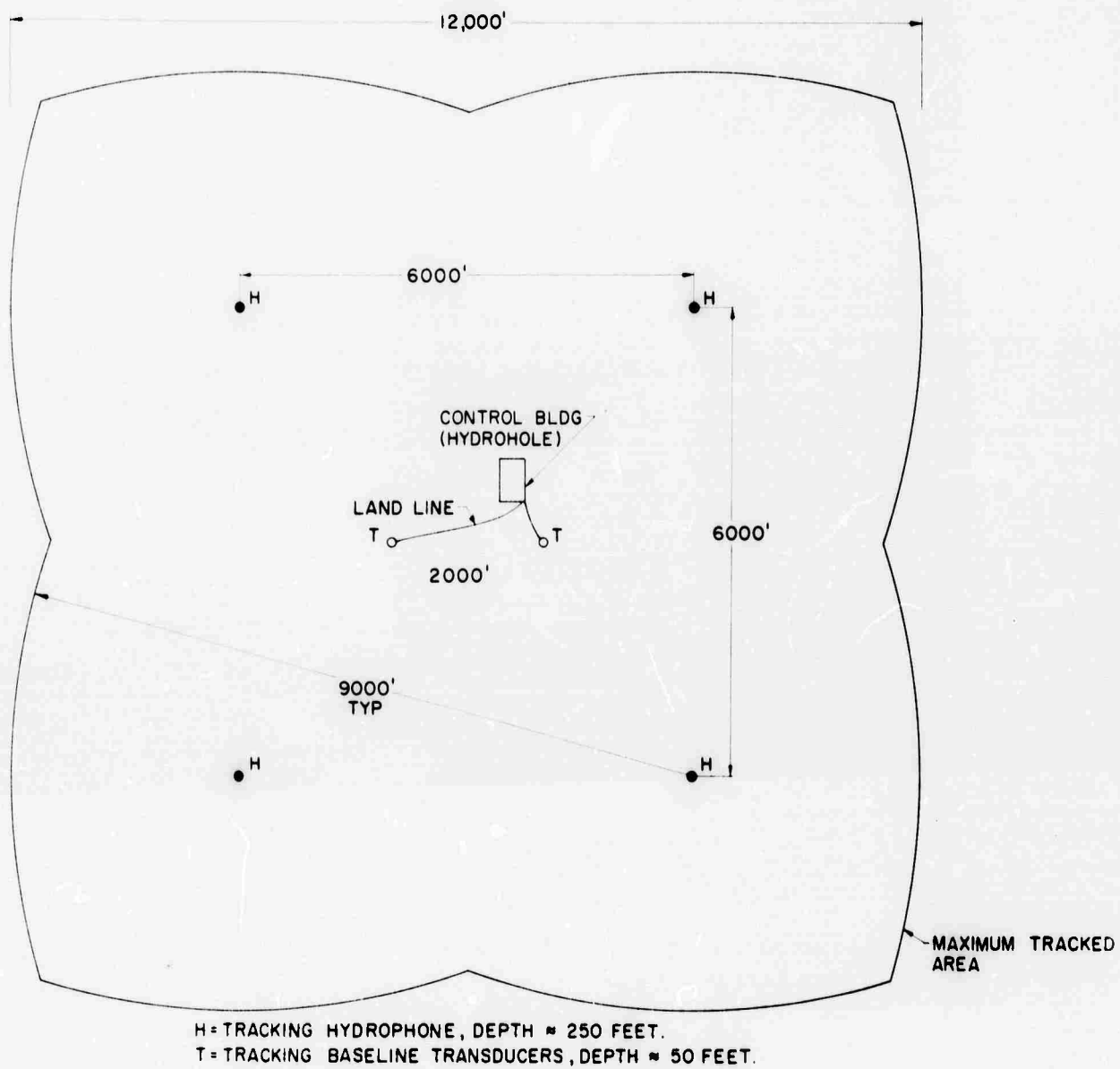


Figure 4.6. UARS Tracking System Arrangement

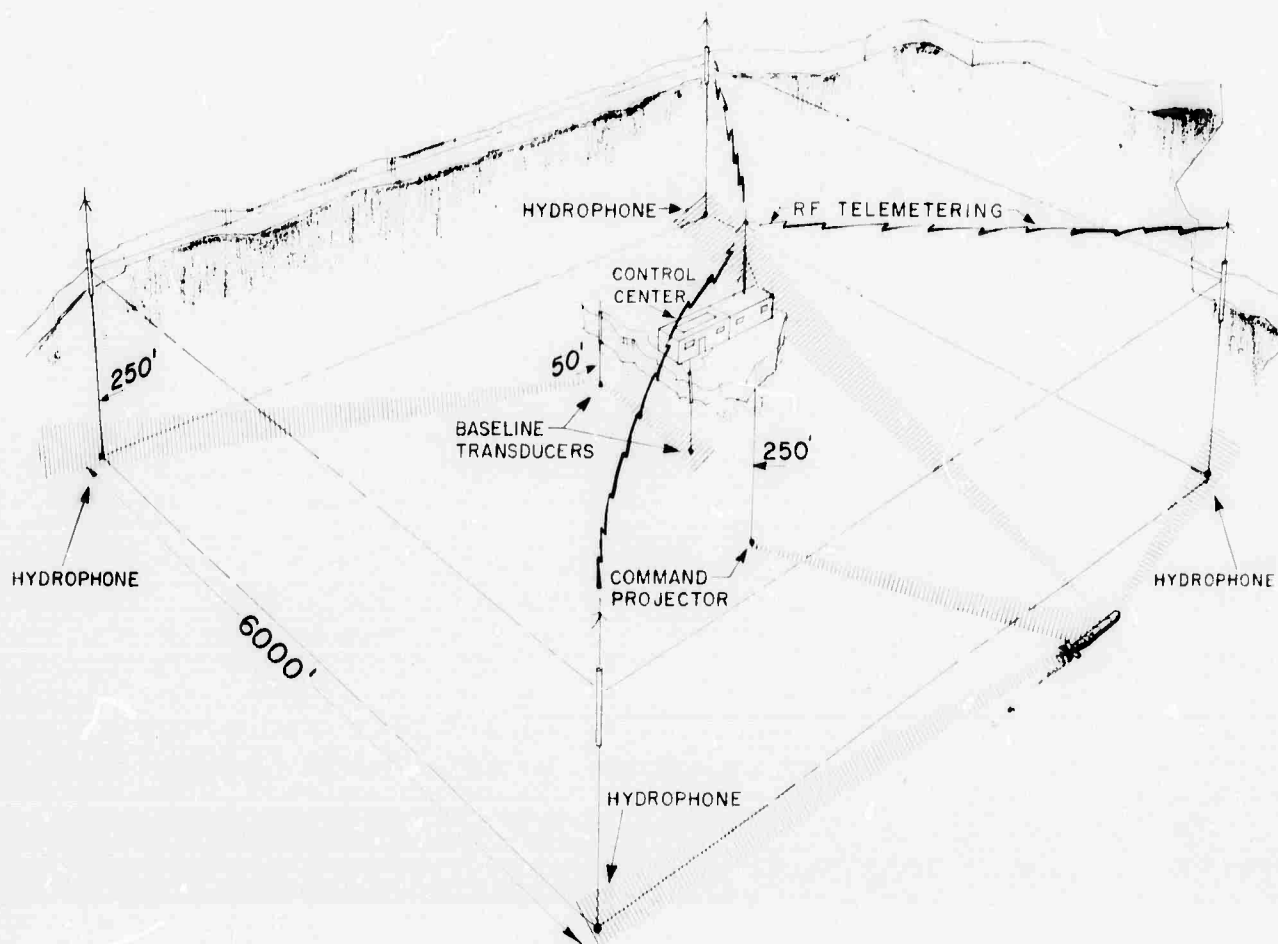


Figure 4.7. Tracking and Command/Communication System Conceptual Layout

into the tracking and data acquisition system. The transit time of the acoustic pulses between the baseline transducers is also monitored at the control building. The command transducer is suspended through the ice in the control building and is at roughly the same depth as the hydrophones.

The hydrophone assembly is shown in Figure 4.8. The hydrophone itself is suspended on a cable from a buoyant container which houses an acoustic receiver and RF telemetry system. The batteries which power the hydrophones are located in the sea water to maintain a constant relatively warm temperature. They can be recharged from the surface. The four hydrophones are suspended at preselected, known depths of 250-300 ft below the ice to reduce signal interference. Interference of direct and reflected signals is discussed in the next section.

The baseline transducer structure is presented in Figure 4.9. Each transducer is mounted on the rigid vertical beam of a buoy frozen into the

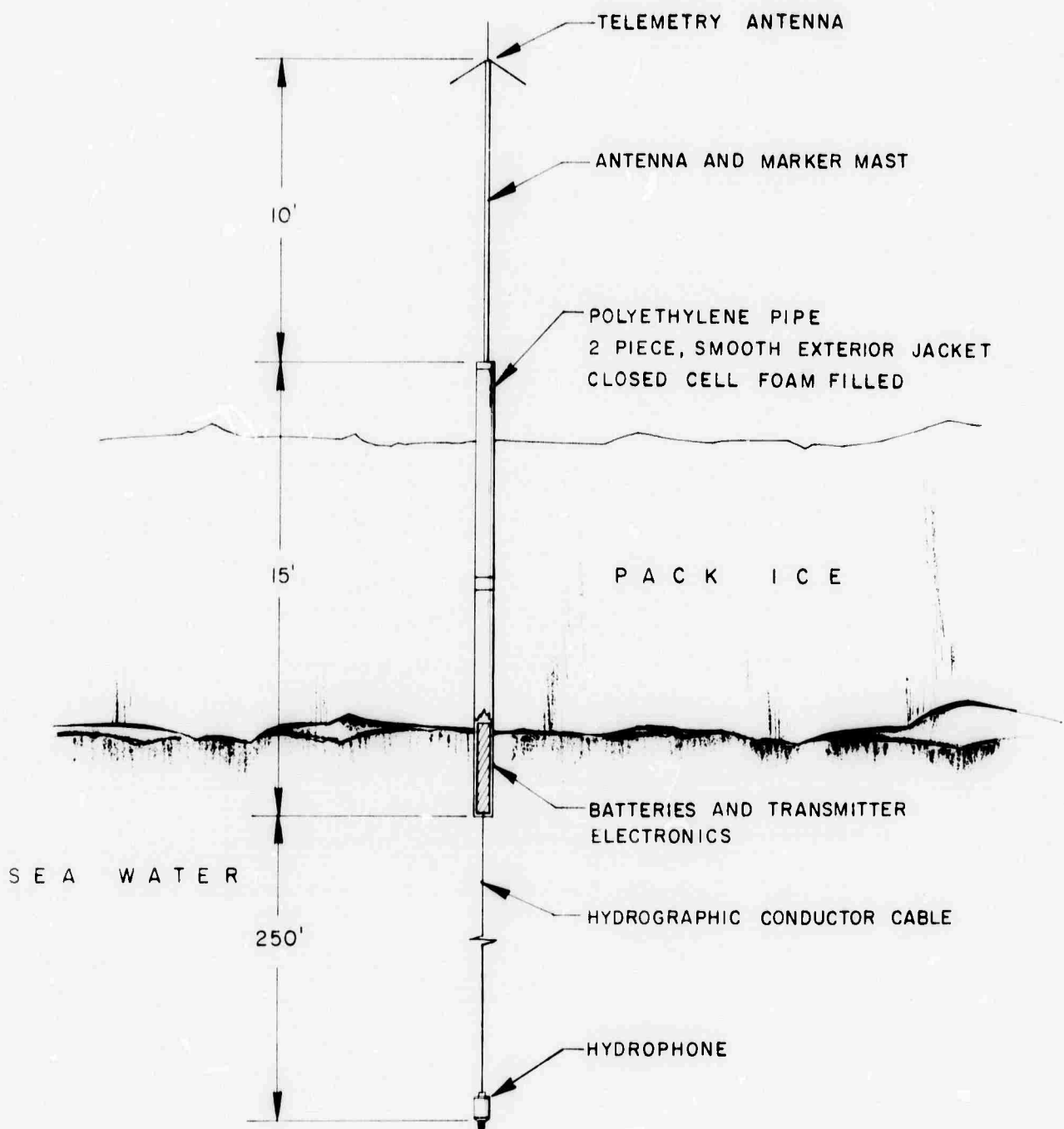


Figure 4.8. Tracking Hydrophone Buoy



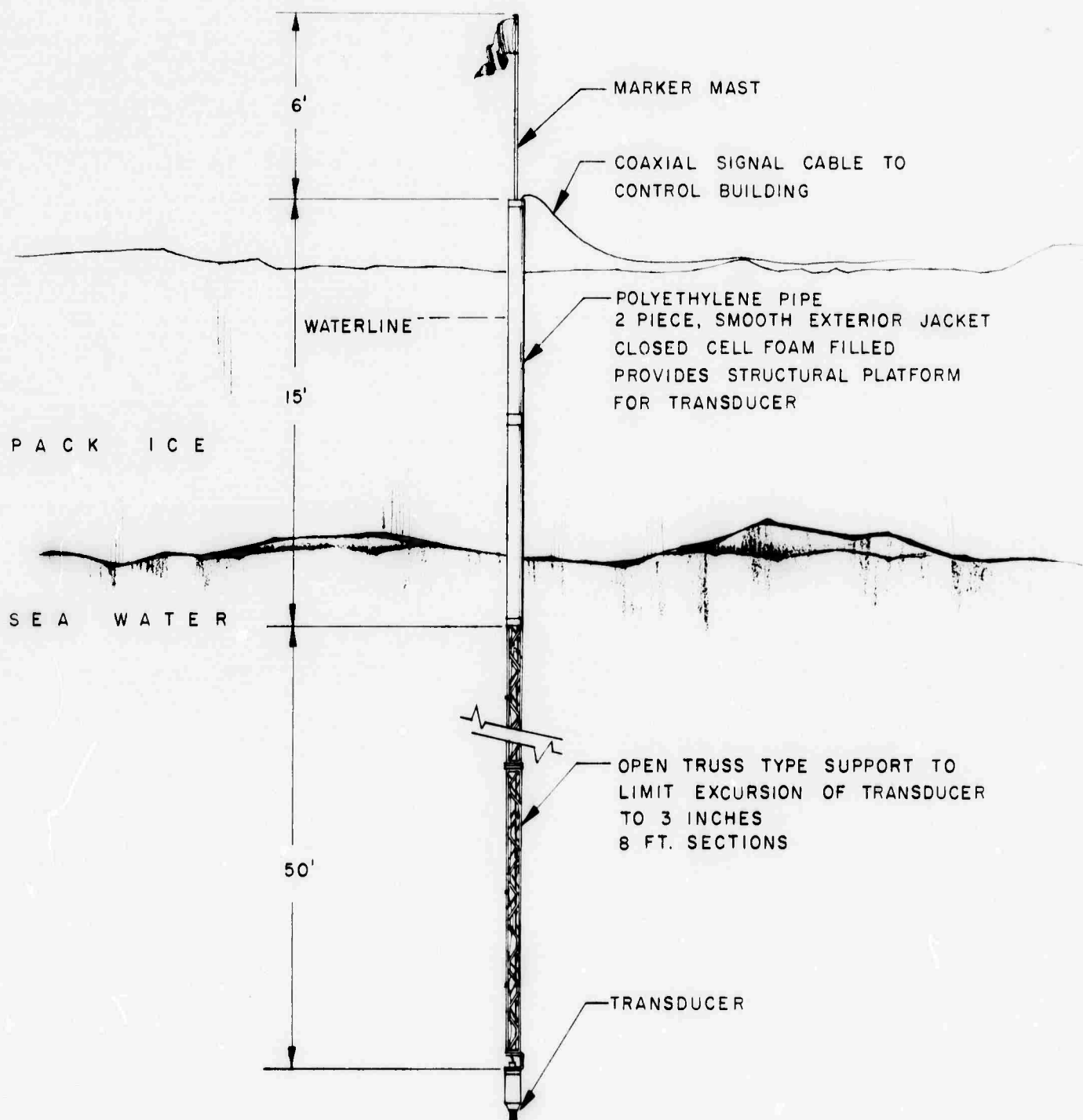


Figure 4.9. Tracking Baseline Transducer Buoy

pack ice. A coaxial cable connects each baseline transducer to the control building. The reference baseline is taken as the acoustically measured distance between the two transducers. To achieve a reliable, direct acoustic path between these two transducers, they are mounted 50 ft below the ice.

In the UARS acoustic tracking system, a common time base is established by synchronizing very stable clocks at the control building and within the submersible. All on-vehicle recorded data is referred to the clock in the submersible, and all externally recorded data is referred to the clock in the control building. During operational tracking, the vehicle projector emits an acoustic pulse every 2 seconds and slant ranges to the hydrophones are determined from velocity-time calculations. The hydrophone positions are continuously measured acoustically with respect to the transducer baseline so that the frame of reference is always current. Periodic measurement and correction of the sound velocity profile will also be made to assure the required tracking accuracy. An analysis of time series oceanographic data taken at T-3 during the past year indicates that a biweekly updating of the profile should be adequate for this purpose.

#### 4.3.4 COMMUNICATION

In order to control the UARS accurately and to ensure its reliable recovery, an acoustic communication link with the vehicle is employed. The system utilizes a common frequency for command, tracking, and vehicle data transmission. When operating acoustic telemetry near an interface such as the ice-water boundary, one of the principal problems is that a signal reflected from the boundary may be superimposed upon the direct path transmission and interfere with the information content. There are several techniques available to minimize this problem; however, the direct approach, the one we have taken, is to provide a geometry and pulse length which preclude the overlap. In an isovelocity medium, the maximum length pulse that can be received free from interference is approximately

$$\Delta L = \frac{2h_1 h_2}{D},$$

where  $h_1$  and  $h_2$  are the depths of the acoustic elements below the reflecting plane, and  $D$  is the horizontal separation. One of the acoustic elements (UARS projector) is normally 50 ft below the ice. At a range of 6000 ft, and with the other acoustic element about 500 ft deep, there is a 1.8 msec time difference between direct and reflected paths. Correcting this example for the actual sound velocity structure in the central Arctic (as measured at T-3 during Jan-May 1970) one finds a depth of about 300 ft will provide the same clear pulse time.

It was determined that the minimum data transmission requirements would be satisfied by a 10 bit code. Various keying options, their bandwidth constraints and acoustic system interactions were considered before deciding to employ a single frequency, 100% phase modulated (180° phase reversal) code. Transmission experiments using water paths in excess of 1 mile established

that a minimum of five cycles of the carrier was necessary to reliably establish phase reversal at modest signal-to-noise ratios. At the selected frequency of 50 kHz, a 10 bit code with five cycles defining a bit will require a 1 msec pulse. For practical communication, three additional bits are required for pulse recognition and phase locking and one for parity. The required overall pulse length is 1.4 msec. Assuming that the submersible would be traveling at a depth of 50 ft, a hydrophone depth of about 250 ft should be adequate to prevent pulse overlap.

The code structure is shown in Figure 4.10. The upper band represents the format of the command code, while the lower band represents all other codes. The first three bits of each code format are used for pulse recognition and receiver phase locking. The next two bits, 00, identify a command message to the vehicle. The type of command is specified in the next four bits, and the magnitude of the command by the four "count" bits. The parity bit validates the message. For example, the four "command" bits may identify any of 16 functions such as "change of course to port" and the four "count" bits may identify any of 16 preselected angular increments. The other codes may include data messages from UARS's acknowledgment of commands, or reports on system performance. Projectors other than the baseline transducers may also be employed for some system applications. A Bottom Navigation Buoy



Figure 4.10. Acoustic Communication Binary Code



used by the process controller to determine the locations of the four hydrophones. The separation distance between the baseline transducers is expected to be quite stable. However, the acoustic transit time between the two elements is monitored on each transmission with a time interval counter. If the distance changes during a vehicle run, this will be indicated by a change in acoustic transit time and the new baseline time (or distance) would then be provided to the tracking system by means of a keyboard entry.

The acoustic data from UARS includes the operating depth (transmitted periodically or whenever there is a "status" change) and the nominal distance to the ice undersurface measured by the middle beam of the profiler. This approximate elevation of the ice underside and the corresponding position and time is output by the process controller to a small line printer and a position plotter. Inspection of this output provides the necessary control information to the experimenter.

Commands to the UARS are sent via the command projector (see Figure 4.7) suspended below the control building. A multiple-switch control code generator is available to the experiment controller to generate the desired command. The command transmission time is controlled by the process controller so that signal overlap at the vehicle is avoided. When UARS receives a command, it is acknowledged with a "status" report as provided for in the code structure (see Figure 4.10). This acknowledgment is listed on the printer output.

After completing the run, the UARS internal recording, which is in digital binary format, is first scanned to detect anomalies in the data or vehicle performance. The scanner system consists of a tape reader compatible with the UARS tape system, a digital-to-analog converter, and a multi-channel strip chart for analog data output. The correlated data output presented in this manner provides an indispensable tool for field maintenance and system trouble shooting as well.

After data scanning, the vehicle tape record is transferred to standard computer tape and reformatted. The vehicle data is highly compressed in order to maximize the total number of bits; to bring to standard format, additional gaps have to be created to allow word separation. The final output of all field data then will be in a tape format which can be directly operated upon by a standard computer.

After a run, the vehicle data and the timing data (tracking) exist on two separate tapes. If another tape unit were available, the data could be merged (on one tape) in the field and a significant amount of data analysis accomplished. For extended deployment periods, this capability should definitely be available. It is not absolutely necessary for the initial deployment of the UARS system.

#### 4.4 FAIL-SAFE LOGIC AND EMERGENCY RECOVERY PROCEDURES

##### 4.4.1 FAIL-SAFE LOGIC

Reliable operation of the UARS is achieved by careful component selection, system design, and redundancy. For example, the main battery and the reserve battery when connected in parallel are diode blocked to prevent discharge of the reserve into the main battery. This arrangement allows full use of all available stored energy in an emergency.

The high probability of recovery in the event of a subsystem failure is ensured by providing a combination of built-in logic, operator command options, homing technique alternatives, and practical recovery options should the vehicle come up under the ice.

The ability to maintain acoustic communication with the UARS is a fundamental requirement for recovery by the normal method (acoustic homing into the capture net). The vehicle is not released from its launching sling until the propulsion motor is operating, tracking is established, and the acoustic command link is operative.

If the vehicle tracking signal is lost near the extremities of the tracking area, the operator will command a vehicle course reversal to return it to the area of stronger tracking signal strength. If the UARS fails to receive a command communication from the controller for a period exceeding 5 minutes, the vehicle course is automatically reversed and an alert code transmitted to the controller. The UARS is programed to remain on this course for 10 minutes. During this period, if communication with the controller is again established the run can be continued normally. If this does not occur, the logic will send the UARS down to a deep preset depth, cause the vehicle to circle in a spiral of increasing radius, and activate the homing system. The experiment controller will turn on the homing beacon whenever he fails to receive tracking communication signals from the UARS, or when he sees uncommanded course changes in the vehicle which result from internal logic decisions, or when the communication code from UARS fails to acknowledge receipt of a command. After a 1-hour spiral search without beacon acquisition, the propulsion and all other internal systems except the tracking transmitter are shut down. Thereafter, the vehicle will rise to the ice underside because of its slight positive buoyancy. If the tracking information is being received by the hydrophones, the vehicle coordinates can be determined and emergency recovery procedures initiated.

If the homing system fails, but the tracking and communication systems are operable, the operator can command the vehicle back to the recovery hole and attempt to strike the capture net with a combination of tracking data and visual observations.

If UARS dives below the maximum preset limit, the propulsion motor is automatically turned off to prevent the possibility of hull collapse. Power is returned when the vehicle rises above the depth limit. The operator can attempt to correct the condition by commanding a different depth. If that

fails, an attempt can be made to steer the UARS to the desired recovery area, although progress may be quite slow because of the on-off motor operation.

#### 4.4.2 EMERGENCY RECOVERY

In the event that a failure results in propulsion power shut-off, the vehicle will float up to the undersurface of the ice unless water leakage into the vehicle was the cause of failure. In the latter case, the vehicle will sink and be lost since no reasonable recovery technique exists.

Vehicle location is the basic problem in emergency recovery. Installed in the afterbody of the UARS will be a recovery pinger and dye marker system. The pinger operates from self-contained batteries and is turned on upon immersion in water. It is secured in place with a soluble link which will release after 14 hours submergence and allow the pinger to drop several hundred feet below the vehicle on a line tether to achieve a more reliable acoustic path for detection. The same soluble link will also release the dye marker.

The location of the pinger will be established by triangulation. Several holes will be drilled through the ice with an ice auger and a directional hydrophone receiver will be used to establish the direction to the pinger. An accuracy in the vehicle position of better than 50 ft should be achievable with three or four observations. Locating the vehicle by this process may be time consuming, therefore the pinger is designed to operate for about 21 days.

After the vehicle has been located, a 2 to 3-foot minimum diameter hole will be cut through the ice. A diver, tethered to the surface, will locate the vehicle and attach a lifting line to a nose hook. A small weight will be attached to the tail so that the vehicle hangs nose up at the recovery hole. Man power can be used to bring the UARS to the surface, but a hoist will be used to lift the vehicle free of the water and load it on a sled for transportation back to the hydrohole hut. The hoist normally at the hydrohole will be used for this operation.

A variation of this procedure is applicable if the UARS position under the ice can be determined from its acoustic tracking projector which should continue to operate until battery exhaustion. The tracking signal can be used for location, similar to the pinger system described above. A trial hole will be drilled in the vicinity and a tracking projector lowered through the hole and its coordinates determined acoustically. From the locations of two or more such holes, the relative position of the UARS can be established within a few feet before making the recovery hole.

A technique for making launch and emergency recovery hydroholes, as well as for coring out instrumentation frozen into the ice, has been developed and tested in the arctic environment. This technique is discussed in section 6.1.

## 5. DESIGN OF THE UNMANNED ARCTIC RESEARCH SUBMERSIBLE (UARS)

### 5.1 GENERAL

The general design characteristics for the Unmanned Arctic Research Submersible (UARS) are given in Table 5.1. The bases for these design values are discussed in the following sections which describe the hull design and the various component systems of the vehicle.

Table 5.1. UARS Design Specifications

MAXIMUM OPERATING DEPTH	1500 FT
SPEED	3 KNOTS
DISPLACEMENT	APPROX. 1000 LB
OVERALL LENGTH	APPROX. 10 FT
DIAMETER	19 INCHES
PROPULSION	(PRESSURE EQUALIZED) 1/4 HP DC MOTOR
POWER SOURCES	
MAIN BATTERY	SILVER-ZINC, 260 A-h AT 24 VOLTS
RESERVE BATTERY	SILVER-ZINC, 60 A-h AT 24 VOLTS
ENDURANCE	12 HR MAXIMUM
(based on estimated load of 10 A for propulsion motor and 15 A for instrumentation and control systems)	
OPERATIONAL NET BUOYANCY	+10 LB

Occasional reference will be made to the Self-Propelled Underwater Research Vehicle (SPURV) described in Ref. 1. These vehicles (two are in use) were designed and built by APL for deep ocean research and are major components in the oceanographic research program presently being conducted by this Laboratory. While use is made of the technology developed in the design of SPURV, the arctic submersible is specifically designed for under-ice operations and is not merely a reconfiguration of SPURV. Major design differences exist in nearly all components because of the different operational goals, depth requirements, environmental conditions, recovery techniques, tracking and command systems, and fail-safe techniques.

### 5.2 PRESSURE HULL DESIGN AND COMPONENT LAYOUT

Figure 5.1 is a cross-sectional view of the vehicle with the major hull design features and component layout. Some blocks indicate envelope volumes of the particular component rather than a pictorial view.



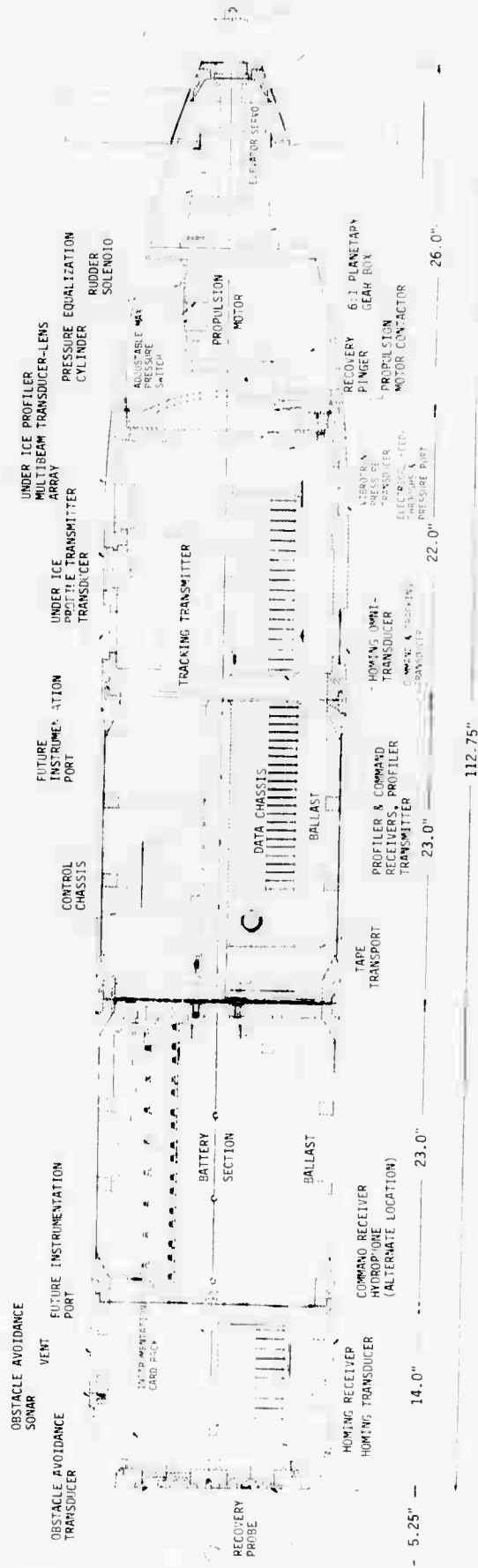


Figure 5.1. Cross-Sectional View of UARS

The pressure hull is designed for a maximum operating depth of 1500 ft with a calculated crush depth of 2800 ft. In the design of pressure hulls, internal volume, shape, construction material, depth capability, weight and payload capability are factors involved in a trade-off analysis. In this case, the hull size was determined principally by the space requirements of the components to be carried in the hull. A cylindrical hull shape was used to obtain a relatively high pressure capability with a low drag profile. The material selection (aluminum and Fiberglas), fabrication techniques, and joint design between sections are based on previous hull design of proven depth capability. A payload requirement was determined on the basis of known component weights for power, propulsion, vehicle control, and presently planned instrumentation -- with an allowance made for future instrumentation growth.

The vehicle comprises five small sections: a pressure hull consisting of four sections, and a flooded tailcone section. The vehicle can be broken down into individual sections for shipment to and from the test site. The size and weight of each section is compatible with light aircraft transport capability.

The sections containing transducer penetrations, the joint rings and all ribs will be made of 6061-T6 aluminum. The shells of the two sections aft of the nose section and a large portion of the tailcone will be made of filament-wound reinforced plastic.

The battery section is located forward of the vehicle center of gravity to counteract the large "nose up" pitching moment from the free flooded afterbody. Ballast below the center of buoyancy will counteract the torque of the propulsion motor.

The tracking transmitter transducer is located directly below the profiler multibeam transducer-lens array so that the tracking positions can be easily correlated with the profiler data. An alternate location for the command receiver transducer (hydrophone) is included in the nose section. This would be available if the operating frequencies for the command and tracking functions have to be separated in order to reduce surface or bottom reverberation interference, or if the acoustic noise level in the present location from the propulsion motor is higher than expected. "Pop-out" transducer units will be used in these locations to protect them from damage during handling of the vehicle. The transducer element in these units is mounted on a spring-loaded pressure-actuated piston which extends the transducer from the vehicle hull when the external water pressure exceeds approximately 6 psi.

The obstacle avoidance sonar transducer and the homing receiver transducer are mounted on a removable nose plate in the nose section. This nose plate approach allows for future addition of watertight electrical connector penetrations and mounting of additional instrumentation at minimum cost.

Spare transducer mounting ports on the top side of the nose and aft sections of the pressure hull have been included as alternate locations for the command and tracking transducers when making runs with the vehicle at depths very much greater than that of the tracking range transducers.

Normal servicing between runs will be accomplished by separating the vehicle at the joint just aft of the battery section. This provides access to the following: the battery, for charging or replacement with a fully charged battery; the data chassis, for changing magnetic data tapes and setting new run depths; the control chassis; and, in particular, the power control panel on the front of this chassis which contains the switches for starting the vehicle, instrument calibration, initial setting of gyro heading, and control system checkout. The data chassis, control chassis, and battery will be mounted on slides within rails fixed to the hull so that they can be easily removed for servicing.

### 5.3 PROPULSION UNIT

A vehicle speed of 3 knots was chosen to match the initial research mission requirements. Drag calculations have been made for a vehicle with UARS's dimensions and shape operating at this speed. The propulsion motor horsepower requirement was calculated using these drag values and estimates of propeller and gear train efficiency. The value of drag is dependent on the precise vehicle shape and appendages and the angle of attack at which it travels through the water. A range of values was obtained from a minimum of 0.1 hp to a maximum of 0.25 hp.

A conventional approach to propulsion system arrangement is precluded by power losses in rotating shaft seals across the pressure differential that exists between the interior of the vehicle and ambient depth, and by the catastrophic results of leakage upon a vehicle which is nearly neutrally buoyant. The approach taken was to place the motor in a thin-walled container filled with a pressure-equalized, non-conducting fluid. A secondary seal separates the fluid and sea water; the fluid pressure is maintained slightly higher than ambient so that sea water will not enter the motor in the event of minor leakage or seal wear. This arrangement unfortunately creates trim problems in that placing the motor, gear box, and equalization cylinder aft of the pressure hull in a non-buoyant tailcone produces a tail heavy condition. The feasibility of extending the pressure hull further aft while retaining the "canned motor" approach by enclosing it within an internal pressure vessel (itself contained within the pressure hull) was investigated as a possible means of reducing the trim problem without increasing vehicle length. This attempt was not fruitful, but it clearly showed the advantages, from a reliability and maintainability viewpoint, of the present arrangement shown in Figure 5.1.

Both ac and dc motors were investigated to determine the most suitable unit for this application. An ac motor would require a solid state dc-to-ac inverter to provide the drive power and special "start up" circuitry. The ac motors exhibit good speed regulation and do not have the commutation problems inherent in dc motors (particularly in flooded motor operation). On the other hand, the overall efficiency of the inverter-motor combination is low, the cost is high, and the weight and space requirements are much greater than for a dc motor of equivalent horsepower.

A dc motor operating in the flooded configuration was chosen. A manufacturer of permanent magnet-type dc motors was located with "off the shelf" motors satisfying the voltage, speed, size, and weight requirements of the planned vehicle configuration. These motors were not designed for operation in a fluid and require some modification (e.g., potting of the rotor). One of these motors has been purchased and tested to determine its efficiency when running submerged in Stoddard's cleaning solvent. Test results show an efficiency of approximately 70% (see Figure 5.2) over the output range of 0.1 to 0.25 hp while running in the solvent, as compared to 75% over the same range for "in air" operation (these results were obtained with an unpotted rotor, i.e., as the motor was delivered from the manufacturer).

A 6:1 planetary gear reduction unit will be used, with its housing providing both a mounting flange for attachment to the tailcone of the motor enclosure and pressure equalization chamber.

The propeller is three-bladed, 24 in. pitch, 14 in. diameter, with the hub cone angle conforming to the tailcone shape. The efficiency of the propeller at the 5-knot speed was investigated and calculated to be approximately 70%. This is very near the theoretical limit implicit in the vehicle drag, propeller diameter, and velocity relationship.

### 5.1 BATTERY SUPPLY

Various types of batteries for the vehicle were investigated. A run time of 10 hours was set as a minimum requirement based on planned vehicle missions. A nominal battery voltage of 24 V was set to conform to the propulsion motor requirement, and the total battery load (propulsion motor plus instrumentation) was estimated to be approximately 25 A. These requirements formed the basis for the comparison, shown in Table 5.2, of the three most suitable battery types.

Lead-acid batteries were given consideration because of their low cost, but were rejected because: (1) they have very poor discharge characteristics, (2) special precautions must be taken against spillage and acid fumes, (3) gassing during charge and discharge presents an explosion hazard, (4) they are subject to freezing at arctic temperatures (particularly so, if in a partially discharged condition), and (5) their weight and volume are excessive.

Silver-zinc batteries have been selected because their high energy density matches the requirement for the vehicle to be as small and lightweight as possible to facilitate portability and handling.

For increased reliability the vehicle will carry two battery supplies: a 260 A-h main battery and a 60 A-h reserve battery. The main battery will provide the normal 10-hour run capability. Battery monitoring circuits are included in the design so that should the main battery fail, the reserve battery will be switched on automatically. It will provide slightly more than 2 hours of run time to enable the vehicle to return to the recovery hole.

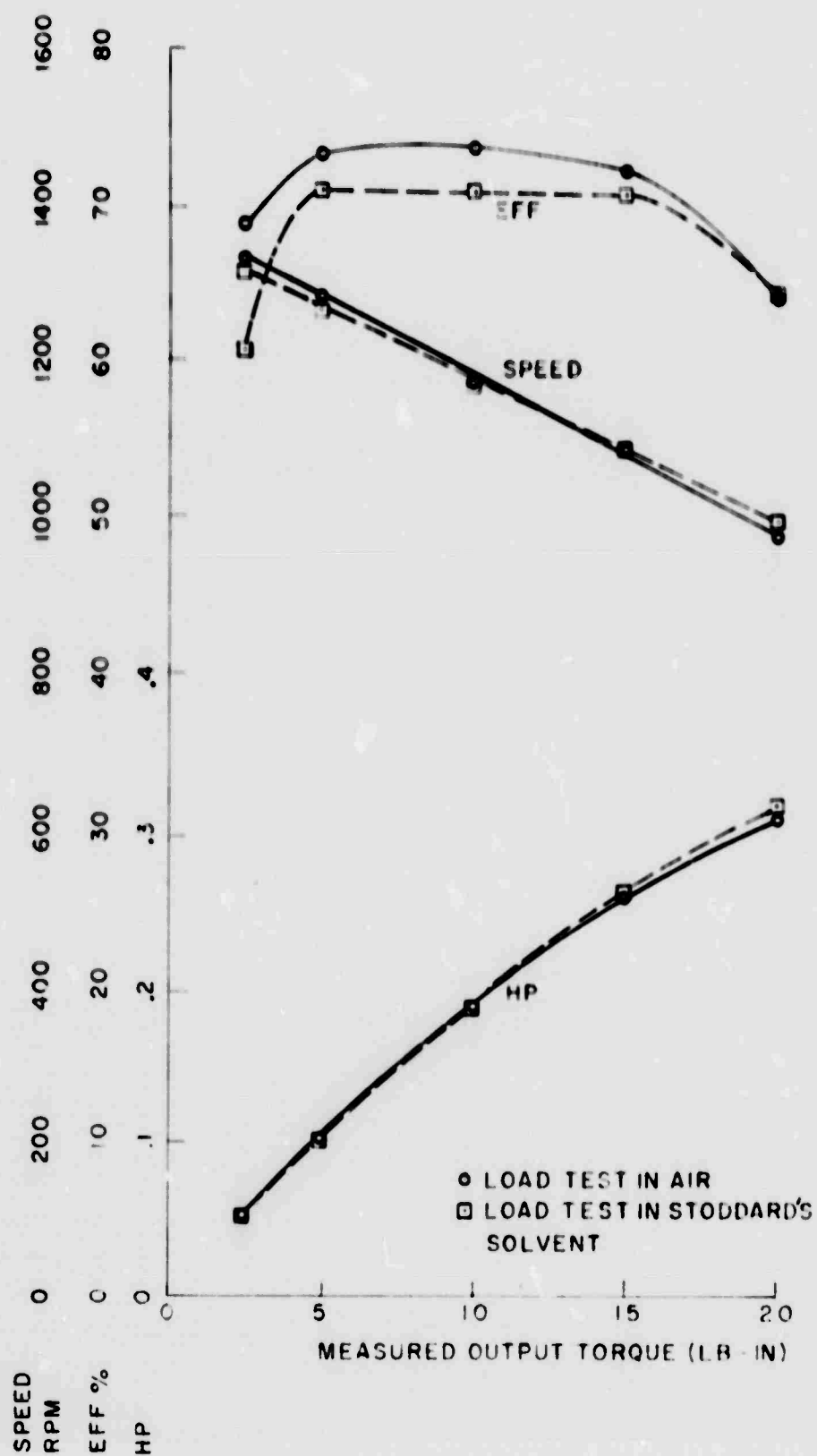


Figure 5.2. UARS Propulsion Motor Characteristics

Table 5.2. Batteries Considered for URS

Type (Particular Cell Units Considered)	Note: Weight, volume and cost given are approximate values based on 10-hour run with 24 V battery, 25 A load (battery packaging not included)				
	Weight (lb)	Volume (cubic ft)	Initial Cost	Recycling Capabili- ty & Storage Life	Low Temp. Storage & Operating Capability
Silver-Zinc (Yardney LR130)	126	1.0	\$4600	80-100 cycles (Deep Discharges) Approx. 2 years	Storage: -55°F to +100°F Operational: -10°F to +165°F. Approx. 5% loss in capacity at 0°C.
Silver-Cadmium (Yardney YS140)	220	1.7	\$7100	200-300 cycles (Deep Discharges) Approx. 3 years	Storage: -55°F to +100°F Operational: -10°F to +165°F. Approx. 10% loss in capacity at 0°C.
Nickle-Cadmium (Sonotone 8LH120)	530	3.9	\$6200	>1000 cycles (Deep Discharges) Indefinite but very long life depending on use.	Storage: -55°F to +165°F Operational: -65°F to +165°F. Approx. 10% loss in capacity when dis- charged at 0°C.
					Excellent discharge char- acteristics. Very low in- ternal resistance. Rugged, leakproof and spillproof.
					Excellent Discharge Char- acteristics. Very low in- ternal resistance. Rugged, leakproof and spillproof.
					Good discharge character- istics. Low internal re- sistance. Rugged and spillproof.

## 5.5 POWER CONVERTERS AND POWER CONTROL

The vehicle will contain solid state de-to-de converters to supply closely regulated +15, +5, and -15 V from the 24 V battery supply. A 24 Vdc to 115 V, 400 Hz sine wave solid state inverter having good frequency stability and regulation is also included to supply power to the directional gyro and the tape transport drive motor.

If the main battery voltage drops below 20 V, the battery monitoring circuits will function as follows:

- (1) The reserve battery will be switched in parallel with the main battery (each battery pack will contain series diodes to prevent discharge of one battery into the other).
- (2) An alarm code will be acoustically telemetered to the tracking station via the tracking pulse to alert the tracking operator to turn on the homing beacon if it is not already on.
- (3) A timing circuit will be started which, after 5 minutes, will activate the homing mode in the vehicle.

Although the reserve battery will not be used during a normal run, its voltage will also be monitored and if its voltage drops below 20 V, a separate alarm code will be sent to the tracking station, and the timing circuit which activates the homing mode after 5 minutes will be started.

The vehicle will contain both a minimum and a maximum pressure switch. The maximum pressure switch serves as a fail-safe device for the depth control system, and its function will be discussed in that section. The minimum pressure switch actuates at a fixed pressure corresponding to a depth of about 25 ft. Its function is to conserve battery power in the event that the vehicle is unable to return to the recovery hole and comes up under the ice or in a lead. This switch will be bypassed by relay contacts until the vehicle has been lowered or dives below 25 ft. Actuation of the pressure switch will energize the bypass relay which will hold itself on through holding contacts. When the pressure switch deactivates, power will be disconnected by means of control relays from all components except those necessary for operation of the tracking transmitter. This transmitter can then serve, along with the recovery pinger, as an acoustic source for locating the vehicle's position under the ice.

A motor control circuit will be provided which will start or stop the motor on the basis of inputs from the acoustic command system. If the vehicle loses commands, goes into a spiral search for the homing signal, and does not pick up either commands or the homing signal over a period of 1 hour, the motor will be shut down.

Reed switches, which can be magnetically activated from outside the pressure hull, will serve the following purposes:

- (1) To turn off power to all components within the vehicle. This would be important if it were necessary to send a diver down through the hole to disentangle the vehicle from the recovery net.
- (2) To enable the propulsion motor, rudder solenoids, and tape transport motor just prior to launch.
- (3) To set gyro heading.

The power control system will also conserve power during warmup and checkout of the various systems prior to launch by applying power only to those systems necessary for the checkout.

## 5.6 DEPTH CONTROL

A simplified block diagram of the depth control system for the UARS is shown in Figure 5.3. The system is designed for an operational range of 0 to 1500 ft with a depth stability on the order of  $\pm 1$  ft during a horizontal run.

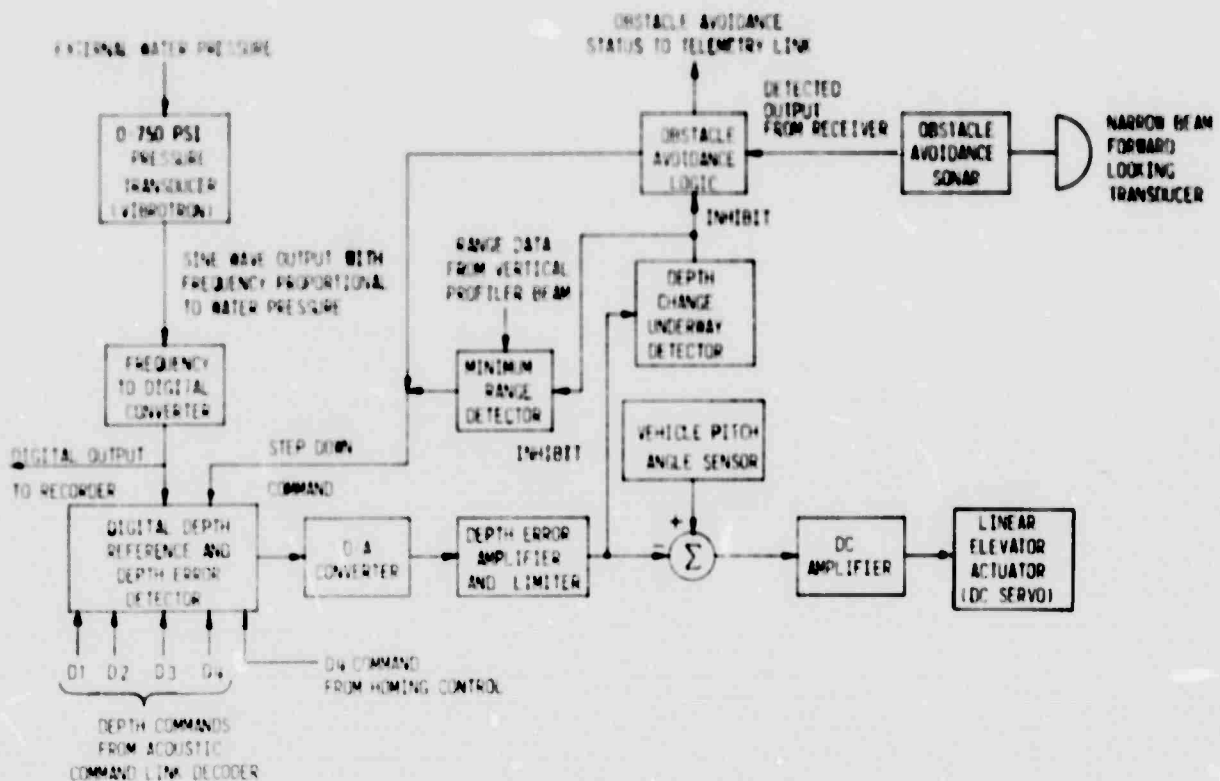


Figure 5.3. Simplified Block Diagram of UARS Depth Control



The pressure sensor selected for the depth control system is a Vibrotron<sup>®</sup> pressure transducer having a sine wave output with frequency proportional to depth. These units are well-suited for this application because of their low hysteresis, high repeatability, and high resolution. Although these units exhibit good temperature stability, the transducer will be enclosed in a temperature-controlled oven because of the large operational temperature range expected and the depth accuracy desired. The sine wave output is desirable because it is relatively insensitive to noise at the output and is easy to convert to digital form.

A digital depth reference is used (see Ref. 2 for a detailed description of a similar system) to provide a highly stable reference and a convenient means of setting the four preset running depths (i.e., a set of switches representing a binary number for each depth). The submersible can be commanded to go to any one of four preset depths as well as step up or down in small increments from any of the preset depths by means of the acoustic command link from the tracking station. Inputs from the obstacle avoidance sonar and the under-ice profiler will send the vehicle to the next lower preset depth each time a step-down command is received from either of the two units. A command to go to D4 (the deepest depth setting) will be initiated by the homing control circuitry whenever the vehicle starts a homing search.

The digital output from the depth error detector is converted to an analog voltage, amplified, limited (the limiter sets the dive and climb angles), and summed with the pitch angle sensor output. The pitch angle input acts as a depth rate feedback in the depth control loop (see Ref. 3). The output from the summation point is further amplified and fed to the linear elevator actuator.

An analog computer simulation of the depth control system was used to determine vehicle depth stability and response characteristics to step changes in depth assuming a vehicle speed of 5 kn. At the time of these runs, the vehicle shape and dimensions differed slightly from the present design. Although the results obtained are probably representative of the system performance, new body coefficients have been derived and will be used in future simulation runs when actual servo hardware is available. The first runs were used to determine the depth control amplifier(s) gain requirements for satisfactory vehicle response to step changes in depth. Simulation runs were made with a depth control configuration using solenoid-actuated elevators, and for the linear elevator actuator configuration shown. Although the pitch oscillations inherent in the solenoid actuator configuration are small (approximately 1° peak-to-peak), they could produce undesirable variations in the under-ice profile data. These oscillations do not occur with the linear actuator, and a suitable unit has been designed.

Another factor which became apparent in the simulation runs was the necessity to limit the net positive buoyancy. With the preliminary body coefficients, the negative angle-of-attack (nose down) required to offset a net positive buoyancy of +20 lb is about 6° at 5 kn as compared to 2° at 6 kn. This angle can be reduced to about 2° at the lower speed by decreasing the net positive buoyancy to +10 lb and increasing the elevator control surface area by a factor of two over that used in the initial simulation. It is desirable

to keep the angle-of-attack small because of the rapid increase in drag with angle-of-attack.

The obstacle avoidance sonar is included here as a component of the depth control system since its principal function will be to increase vehicle depth to avoid ice keels. The planned operating depth for obtaining the under-ice profile data is 50 ft, and ice keels can extend below this depth. The transducer for the sonar is mounted on the nose of the vehicle with a beam width of  $4^\circ$  between -3 dB points at an operating frequency of 360 kHz. The center of the beam is aligned with the vehicle center line and since the vehicle will have a negative angle-of-attack of approximately  $2^\circ$ , the center of the beam will be directed downward from the horizontal by the same small angle. This is desirable since keels extending far below vehicle operating depth will be detected at maximum range while keels only slightly below vehicle depth will be detected at shorter ranges. Preliminary tests with a breadboard model of the obstacle avoidance sonar indicate that a detection range of greater than 500 ft can be expected on deep keels (those 50 ft or more below vehicle depth) provided the angle of incidence between the sonar beam and the ice surface of the keel is less than  $50^\circ$ . Keels having a greater angle of incidence with the beam, or extending to shallower depths, will be detected at proportionately shorter ranges. These detection ranges are considered more than sufficient to permit the vehicle to dive through several depth ranges (assuming 50-ft spacings between D1, D2, and D3), if necessary, to avoid even the deeper keels which may be present in the arctic basin. See Ref. 4.

A block diagram of the obstacle avoidance sonar is shown in Figure 5.4. The sonar operates at the data rate frequency of five samples/sec giving a maximum unambiguous range of 500 ft. A pulse length of 200  $\mu$ sec is used which corresponds to an in-water path length of about 1 ft. To discriminate against fish, seals, etc., the detector requires pulse elongation of approximately 5 pulse widths (2.5 ft in range) before a valid return is recognized. Since ice keels will, in general, be sloping, an extended return is expected.

A school of fish can also produce an extended return, so a running count is made of the valid returns. These returns cause an up-down counter to count up for two counts. A latch prevents acceptance of more than one valid return per sampling period. Each transmit pulse causes a down count of 1 unit, and also resets the latch. With a low valid return rate (50% or less) the average counter reading is near zero. As the valid returns increase in pulse-to-pulse reception rate, the counter output climbs toward its maximum of 15. When the maximum is reached, an avoidance signal is generated.

When a depth change is underway, the counter is inhibited from up-counting, so that an avoidance signal will not be generated during a change to a new level. This requires attention from the tracking operator, who must monitor profiler data (via the acoustic telemetry link) before commanding a shallower run depth to ensure that the vehicle does not climb into the ice canopy. When a depth change is completed, 14 consecutive valid pulses will be required to generate an avoidance signal; this is approximately 14 ft of vehicle travel.

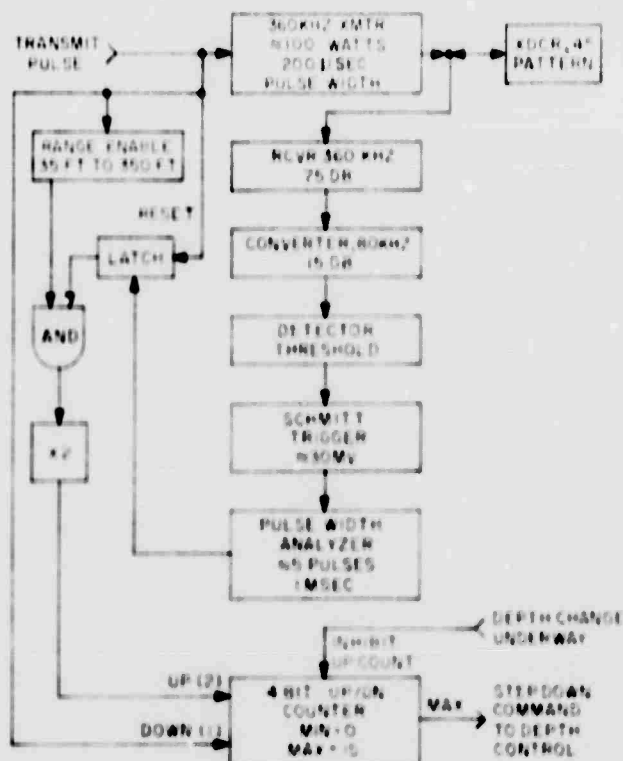


Figure 5.4. Block Diagram of Obstacle Avoidance Sonar for UARS

This system has been breadboarded and tested in local waters, using grazing reflections from the bottom to simulate similar returns from the ice undersurface. The system functioned as intended. Fish returns were identified in some received signals (unprocessed) but were rejected. Field tests at T-3 using a trainable transducer to vary the grazing angle have verified the adequacy of the approach discussed above.

An adjustable maximum pressure switch will be used as a fail-safe device for the depth control system. This unit will be set before each run to actuate at a depth slightly greater than the maximum depth at which the vehicle is expected to operate during that run. If the depth control system fails and the vehicle attempts to dive below the actuation pressure, the motor will be shut off by actuation of the switch and the vehicle will float toward the surface. When the vehicle rises above the deactuation pressure of the switch the motor will restart. The vehicle would presumably again dive to the actuation pressure and the cycle would be repeated. Each time the propulsion motor shuts down an alert code is sent to the tracking operator. Thus, this start-stop sequence should be readily apparent to the tracking operator. If the problem is an incorrect setting in one of the pre-set run depths, this can be corrected by commanding a new run depth. If this fails to correct the problem, the vehicle can be guided to the recovery hole by commanding appropriate headings, even though its progress would be impeded by the start-stop sequence.

## 5.7 HEADING AND HOMING CONTROL

Strong reliance will be placed on the heading control system to bring the vehicle back to the hole for recovery at the end of a run. This is true for normal runs as well as runs that have been prematurely terminated by low battery voltage or loss of command signals.

A simplified block diagram of the heading control system is shown in Figure 5.5. The primary heading reference during a run will be a self-leveling directional gyro. These gyros were originally manufactured by Sperry Gyroscope Co. as part of their C-4 Gyrosyn Compass system for aircraft. They are overhauled, and modified to provide a commutator type output. The modification also includes the addition of a stepping motor and associated drive for stepping the commutator in  $3^\circ$  increments in either a clockwise or counterclockwise direction. Drift rate of the gyro is specified by Sperry as  $0 \pm 8^\circ/\text{hour}$  at a latitude of  $42^\circ\text{N}$  and  $25^\circ\text{C}$ . For this application, the fixed precession rate to compensate for earth's rotation will be adjusted for a latitude of  $80^\circ\text{N}$ .

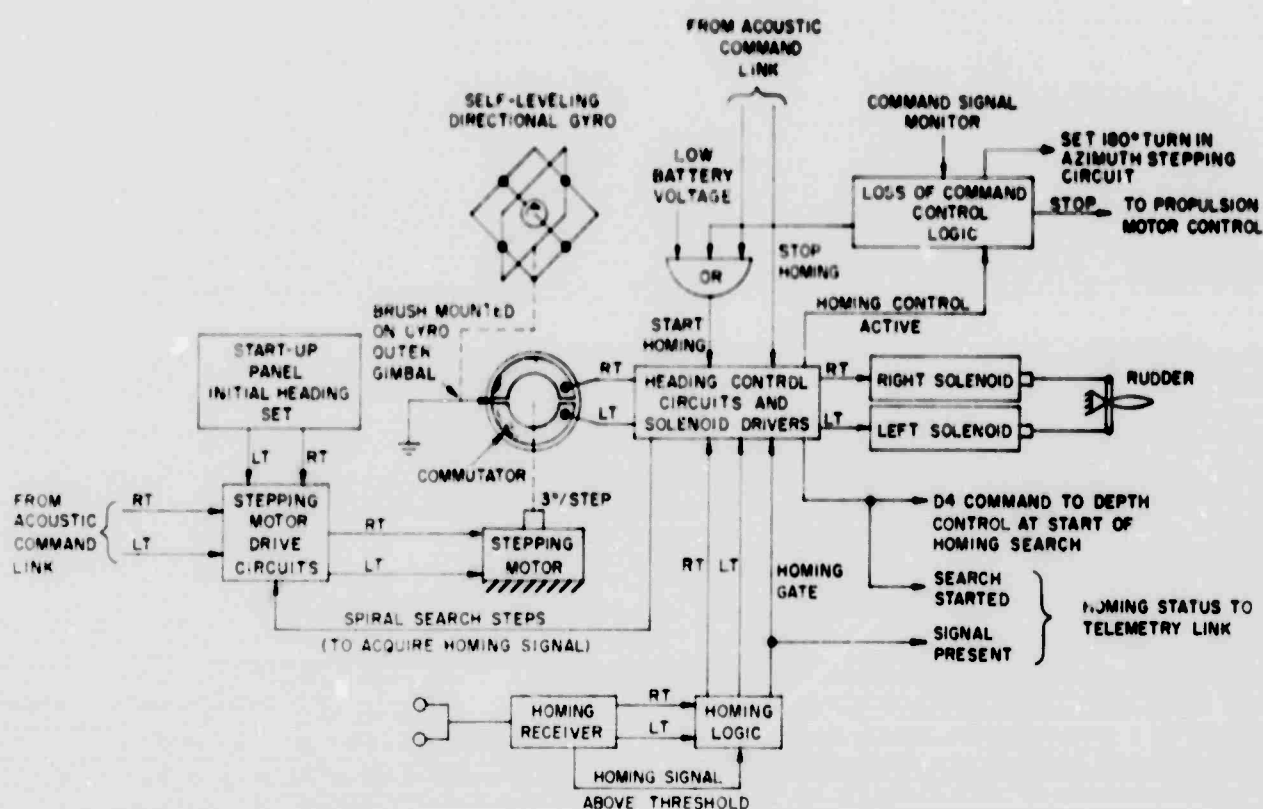


Figure 5.5. Simplified Block Diagram of Heading Control for UARS

The gyro heading will be set before launch. Heading changes during a run are commanded through the acoustic link from the tracking station. To terminate a normal run, the vehicle is first commanded to the heading of the recovery hole. A "start homing" command is sent when it is observed via the acoustic telemetry link (modulation on the tracking pulse) that the homing signal is above the threshold level. The heading control circuits will then switch control of the rudder solenoid drive circuits to the output of the homing receiver. "Stop homing" can be commanded by acoustic link at any time and heading control then reverts to the directional gyro. Thus, if the homing control malfunctions, guidance to the recovery hole will be possible with the normal command system.

If a loss of homing signal occurs while the vehicle is in the homing mode, the homing logic allows the submersible to continue on the same path for 30 sec (approximately 150 ft) and then activates a continuous right rudder. The vehicle will then circle until one of the following occurs:

- (1) the homing signal is reacquired, at which time the heading control again reverts to the homing receiver, or
- (2) the vehicle is commanded to stop homing, and control reverts to the gyro, or
- (3) the motor stops, either by command or because of loss of commands for a 1-hour period, and the vehicle floats up to the ice.

This sequence ensures the vehicle of another pass at the recovery net if it should happen to miss on the first approach. The intercept angle is changed by approximately  $45^\circ$  on each succeeding pass, as illustrated in Figure 5.6, so that a miss because of a low intercept angle will be corrected on the following pass.

Since navigational control during a run requires receipt of periodic heading changes through the acoustic command link, a failure to receive such commands must be detected by the internal vehicle control system and appropriate action taken to bring the vehicle either back to the recovery hole or to a position where command control is again acquired. We have placed an operational requirement on the command system such that commands must be received by the submersible at intervals of less than 5 minutes. These may be redundant commands such as commanding the vehicle to go to depth D1 when the vehicle is already at that depth. If the vehicle does not receive a command for a period of 5 minutes, a "loss of command" sensing circuit actuates a  $180^\circ$  turn in the azimuth stepping circuits which reverses the vehicle course for a period of 10 minutes. This should place the vehicle in the vicinity of where the last valid command was received. If commands are still not obtained, a failure in one of the command link components is assumed and a homing search mode is activated which does the following, in turn:

- (1) activates an alert code to be acoustically telemetered to the tracking station

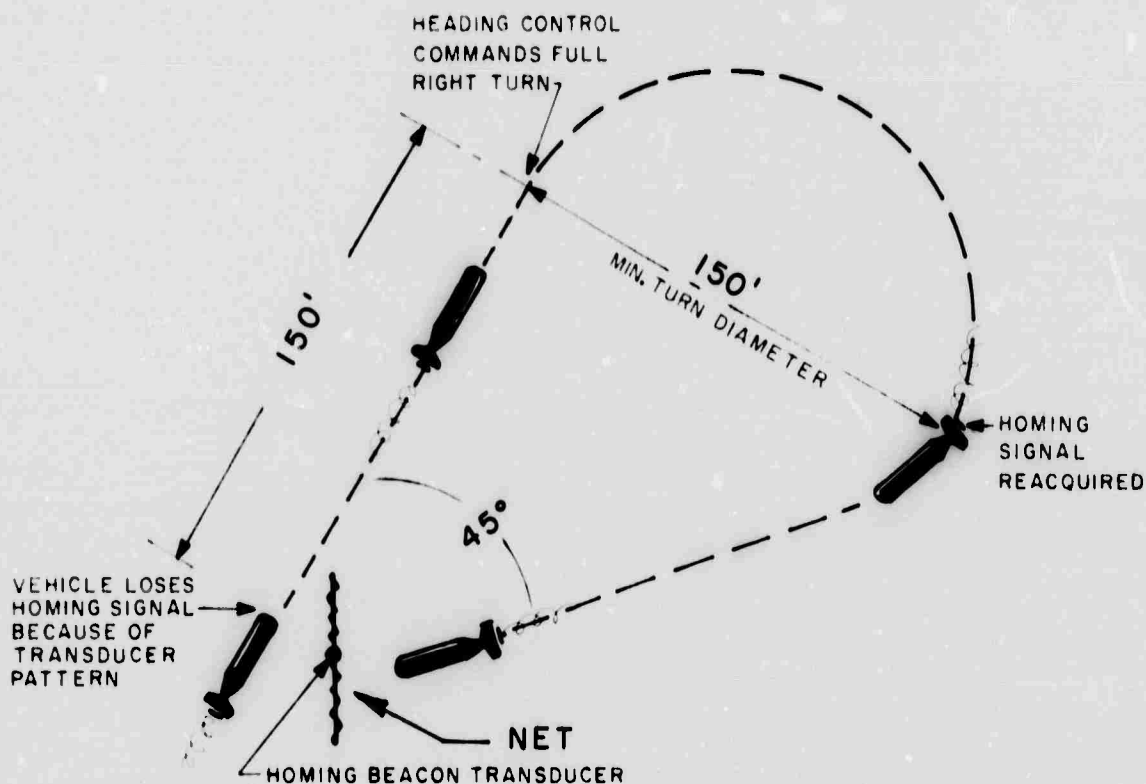


Figure 5.6. Illustration of Vehicle Trajectory After Missing Net Because of Low Intercept Angle

- (2) sends a D4 command to the depth control
- (3) sends steps to the gyro commutator stepping motor at a rate which decreases with time to put the vehicle in a spiral search pattern
- (4) switches heading control to the homing receiver output when the homing gate is positive, indicating satisfactory homing signals are being achieved
- (5) if homing control is achieved, it resets the timer which shuts down the motor after loss of commands for a 1-hour period.

The purpose of sending the vehicle to its lowest run depth (D4) at the start of the spiral search is to reduce refraction and reflection effects on the homing and command signals.

The low battery voltage signals, which were discussed in the power control section, activate the homing search mode in the same manner as described above for the loss of command signals.

The UARS homing system makes use of the signal physics of a sonar pulse from a fixed beacon sensed from a platform moving through a field of stationary

but directional acoustic reflectors to identify the correct beacon direction. A block diagram of the homing receiver is shown in Figure 5.7.

The signal from the homing beacon will consist of a pulse modulated 28 kHz carrier with a pulse repetition rate of 5 pulses per second and a pulse width of 4 msec. The in-water peak pulse power level at the transmitter will be approximately 90 dB (ref. 1  $\mu$ bar at a distance of 1 yd from the transmitter transducer).

Inputs to the homing receiver electronics come from three hydrophones mounted on the vehicle. Two cylindrical PZT hydrophones are located on the nose and spaced  $3/8 \lambda$  (at 28 kHz) from each other. This spacing precludes a phase ambiguity (which could cause reverse steering). They are referred to as the bearing hydrophones since a phase comparison of the homing signals received at these two transducers provides the basic bearing information used to guide the vehicle toward the homing beacon. They are baffled on the side next to the vehicle body, to see forward only, and have -3 dB beam widths of approximately  $120^\circ$  in the horizontal plane and  $50^\circ$  in the vertical plane. The third hydrophone, referred to as the sense hydrophone, has an omnidirectional pattern and is mounted on the underside of the vehicle approximately 5 feet aft of the bearing hydrophones. Homing pulses received at this hydrophone are used to prevent homing on reflected signals. This is discussed in greater detail in the following description of the operation of the homing receiver.

Two three-stage tuned amplifiers amplify the signals received by the right and left bearing hydrophones. Their outputs are fed to zero-crossing detectors  $180^\circ$  out of phase and the pulse output of these detectors is used to feed a flip-flop type phase detector. The output of the phase detector is filtered to remove the 28 kHz square wave component, and the dc component is then passed through two sample-and-hold circuits to positive and negative comparators to provide right and left output commands which are dependent upon the directional bearing of the received signal.

Several logic decisions are necessary to avoid reverberation problems and the possibility of bearing calculations on false signals. An input to a threshold detector is taken from a relatively low gain tap from one of the three-stage tuned amplifiers. When this input signal exceeds the threshold (approximately -100 dBV input), it is rectified and filtered in the detector. The detected signal is then used to trigger a sample pulse generator which provides a 1 msec pulse to the first sample-and-hold circuit. Thus, the first 1 msec of the input signal is sampled for phase and this phase (or bearing) information is stored. The trailing edge of the sample pulse triggers a 100 msec pulse generator which inhibits further triggering of the sample pulse generator for 100 msec. The 1 msec sample assures that only the phase information in the first part of a pulsed signal (which is less likely to be compromised by reverberation) is stored in the hold circuit. The inhibit pulse then prevents calculations on further signals within the succeeding 100 msec period and thus ordinarily guards against calculations on reflected signals which occur after direct signals.



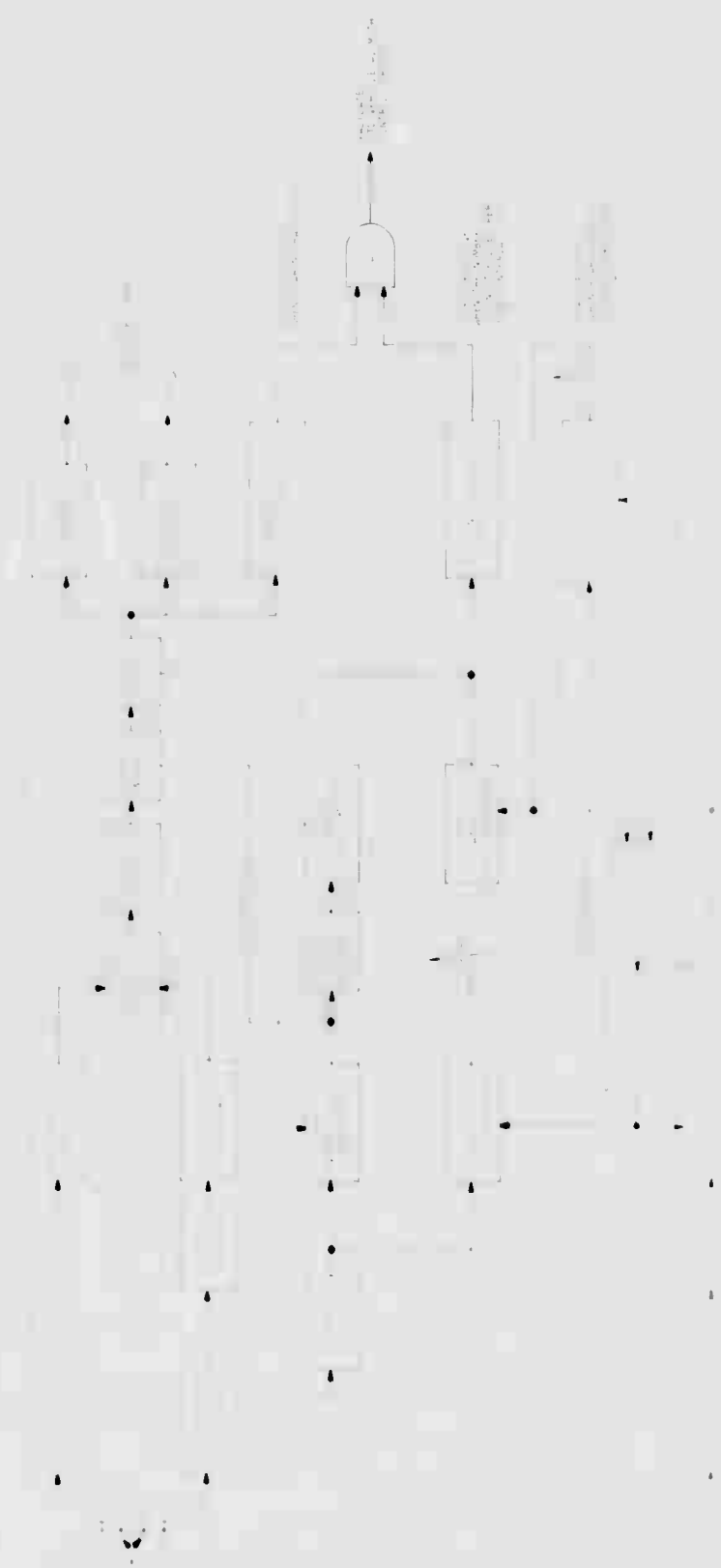


Figure 5.7. Block Diagram of Homing Receiver for UARS



Before transferring the stored sample to the second sample-and-hold circuit, two other tests are made on an incoming signal to determine its validity. The first test is performed by the 3 msec pulse width discriminator. To obtain an output pulse from this circuit, the incoming signal must remain above threshold for 3 msec or longer. Thus, the homing pulse, of 4 msec duration, will produce an output pulse while noise of shorter duration will be rejected.

The second test is performed by a circuit which compares the arrival times of pulses received at the sense and bearing hydrophones. To obtain an output pulse from this circuit, the pulse in the bearing channel must arrive 0.8 msec before that in the sense channel. With a 5-ft separation between the sense and bearing hydrophones, an output pulse is obtained only when the direction to the homing beacon is less than  $40^\circ$  off the vehicle axis (at larger angles, the separation time between pulses is less than 0.8 msec). This test would be unnecessary if the bearing hydrophones had omnidirectional coverage and were always able to pick up the direct pulse from the homing beacon as well as any reflected pulses. Reflected pulses, arriving after the direct pulse, would then be rejected by the 100 msec inhibit pulse on the first sample-and-hold circuit as already discussed. However, because of the low response in the rear pattern of these hydrophones, it is conceivable that reflected pulses might be picked up while direct pulses go undetected when the vehicle is headed away from the homing beacon. The sense hydrophone, having an omnidirectional coverage, will be able to pick up the direct pulses in this situation and the time of arrival test will avoid the possibility of homing on the reflected signals.

Associated with the operation of the pulse arrival time comparator is a 100 msec inhibit pulse generator. This generator is triggered either by the sense pulse or by the output from the arrival time comparator. It then inhibits further outputs from the 3 msec pulse width discriminator circuits in both the sense and bearing channels for a period of 100 msec. This prevents time of arrival comparisons being performed on any reverberation following a direct pulse within the inhibit pulse period.

The output from the pulse arrival time comparator is used to trigger a second 1 msec sample pulse generator which transfers the original phase calculation to the output comparator. These comparators issue a right, left, or no command to the azimuth control circuits depending upon the bearing (phase) indication. This command is held until a new calculation is made.

The remainder of the circuitry is used to further verify the validity of the signals. Unlike the other validity tests, these require the examination of a number of homing pulses and serve primarily during the acquisition phase of the vehicle homing sequence. To obtain a validation signal which is then supplied to the vehicle azimuth control logic, the following two conditions are required:

- (1) The phase (bearing) calculations must not vary in a random manner from pulse to pulse.

- (2) At least 10 pulses must be received within a 3 second period.

The random phase test is applied to the output of the second sample-and-hold circuit. On the block diagram this circuit is labeled "bearing rate detector". It essentially comprises a 1 to 20 Hz bandpass filter, an amplifier, an amplitude detector and an inverter. A positive output is obtained from the bearing rate detector only when the input bearing signal varies at a slow rate (high frequency components are precluded because of the sampling rate -- 5 pps) which is characteristic of a properly varying homing signal. This validation test, used alone, would be insufficient to verify the presence of a proper homing signal since no signal inputs to the system would also be interpreted as a valid signal. Therefore, after this test is passed, a second multiple pulse validity condition requires the receipt of 10 pulses within a 3 second period.

The design of the homing system has progressed from a simple CW system, which successfully operated at 3-mile ranges in Puget Sound, through several stages before the present, rather sophisticated design was attained. The interference noise in Puget Sound is quite different from that to be experienced under the arctic ice. In the latter area, the reverberation or reflection of the beacon signal from the water-ice interface causes azimuthal signal distortion as well as strong Lloyd mirror effects. To a large extent, the latter problem can be ameliorated by using CW pulses. Both CW and pulsed CW system tests in the arctic under-ice environment during April of this year indicated directional ambiguity problems which could be resolved only by a rather complex logic chain.

## 5.8 DATA RECORDING SYSTEM

The data recording system is designed to operate with a low-speed magnetic tape recorder and obtain high-resolution, high density data recording at a relatively low data rate over long periods of time. To accomplish this, all signals are converted to binary form (sampled and converted if a continuous signal) and recorded on magnetic tape using the non-return-to-zero, change-at-one (NRZI) recording method. A nine-track recording head is used on 1/2-inch magnetic tape, and the binary data words are recorded across the tape in a parallel-serial combination using time-multiplexing to separate the various data channels.

The magnetic tape transport design is a modification of a design originated by this Laboratory for use in SPURV. Several of these units have been built and used in field operations with excellent performance. These are limited-purpose units, designed for recording only with no play-back capability. However, they are very compact and have low power drain. Modifications from the SPURV design consist primarily of increasing the number of recording tracks from seven to nine and decreasing the tape speed from 3/4 to 3/8 inch/sec. The reduced tape speed will permit 12 hours of data to be recorded on a single 7-inch reel of 0.5 mil base tape. Nine-track recording is being used in preference to seven-track because of its increasing utilization in many of the newer computer systems (e.g., IBM/360).

The tape transport uses a capstan drive powered by a 400 Hz synchronous motor through a precision gear reducer and flat belt drive to achieve the necessary speed reduction. The 400 Hz power is obtained from a solid state inverter which has a frequency stability of  $\pm 1/4\%$ . This arrangement gives a very precise average tape speed.

Figure 5.8 shows the channel multiplexing arrangement used for UARS data recording. Two characters are required to write a word in each channel (A through J). A character in this context refers to a vertical column across the tape. The basic character recording rate is 120 times per second which, with a tape speed of 3/8 inch per second, results in a tape recording density of 320 characters per inch. Two of the nine tracks are used to record the character clock and a multiplex synchronization pulse. These timing pulses are used in recovering the data from the tape. The other seven tracks contain the data portions of the words in the various channels.

One aspect of the multiplexing arrangement which may not be entirely obvious from the diagram is the timing sequence of the word counter. This

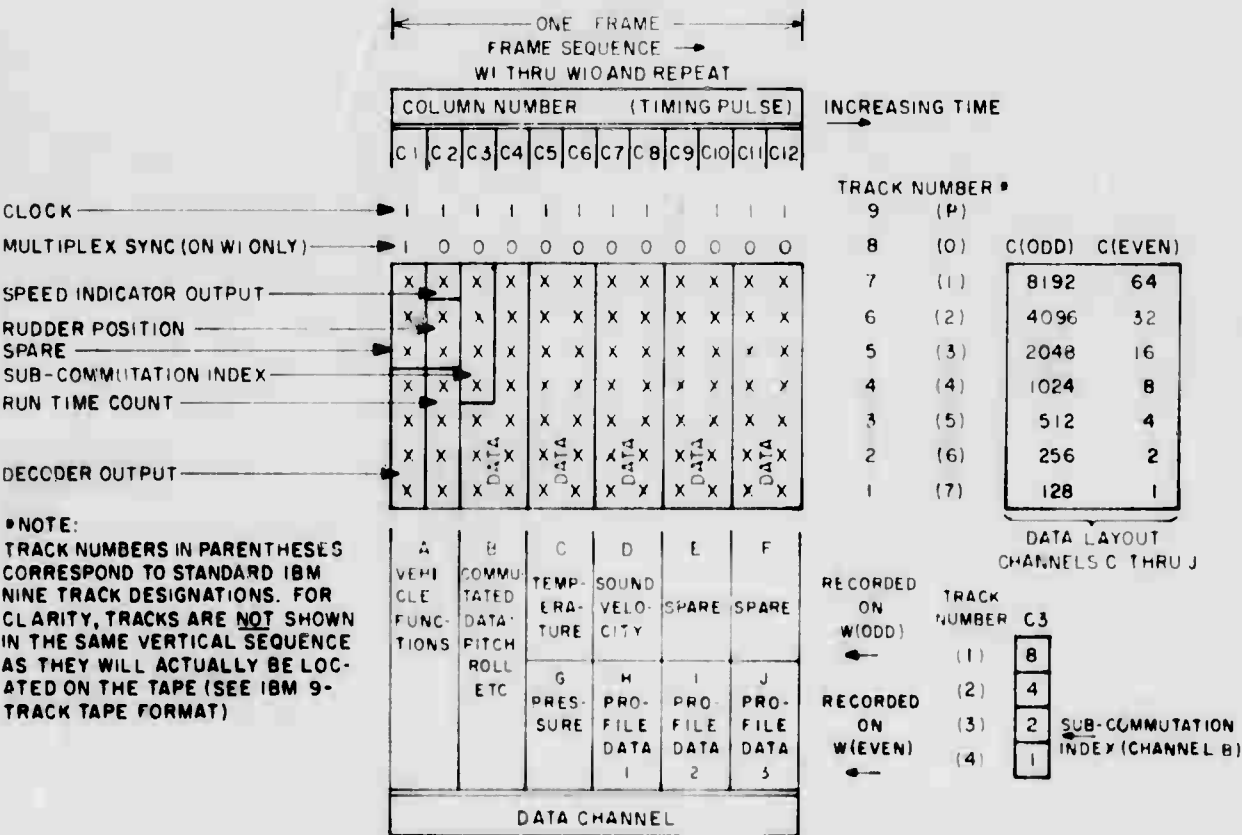


Figure 5.8. Format for UARS Data Recording

counter steps sequentially and repetitively from W1 through W10 with a single step occurring at the completion of each frame as shown. Each channel is wholly, or in part, time-multiplexed in accordance with the word count as well as with the character timing pulses C1 through C12.

Channels C through J are time-multiplexed in accordance with even and odd words from the word counter to provide for inputs from eight sensors at a recording rate of five times per second. Six of these inputs have been allocated based on the planned instrumentation suite, and two are available for additional instrumentation. The recording rate of five times per second corresponds to a data point for each foot of travel at the planned vehicle speed of 3 knots. A straight binary code is used in these channels which provides a capability for recording up to a 14-bit binary number in each word. The first character in a channel word is referred to as the "High Register", and the second character as the "Low Register" with the bit weighting for each register as shown in the box on the upper right side of the figure. The "write" commands for the characters are referred to as High Register Write (HRW) and Low Register Write (LRW).

Channel B contains the output from a 10-bit analog-to-digital converter. In general, all signals to be recorded in this channel will be of a slowly varying nature, such as battery and secondary supply voltages, pitch, roll, etc. The signals are commutated at the input to the A/D converter by a solid state multiplexer which is stepped with the word count. In addition, a sub-commutation is performed on signals which need to be recorded only infrequently, such as battery and supply voltages. At the present time only the W1 position will be sub-commutated. A four-bit index will be sub-commutated. A four-bit index will be included along with the sub-commutated data to identify the particular signal being recorded. The location of the ten data bits in this channel is indicated in the figure and the weighting of the bits is the same as shown for channels C through J in the corresponding bit locations. The location and weighting of the index bit positions are also shown in the figure. A total of 16 sub-commutated signals can be recorded in the W1 position at a recording rate of one every 16 seconds.

Channel A is a "catchall" channel. One of its functions is to record the occurrence of off/on type outputs such as rudder actuations and the vehicle speed indicator output. The sampling rate (recording rate) is ten times per second, and the presence or absence of a bit in the positions shown indicates the on/off state of the function indicated. Four bit positions in this channel are time-multiplexed in accordance with the word count in order to record a 16-bit binary number containing the count in seconds of the elapsed time since the occurrence of the external synchronization pulse at the start of the run. The multiplexing arrangement and the weighting of the bit positions is shown in Figure 5.9. Also included in Channel A is the four-bit binary coded acoustic command last received by the vehicle.

A block diagram of the complete data system is shown in Figure 5.10. A detailed description of the frequency-to-binary conversion used for recording pressure, temperature, and sound velocity, and the A-D conversion used for recording pitch, roll, elevator angle, etc. is given in Ref. 5.

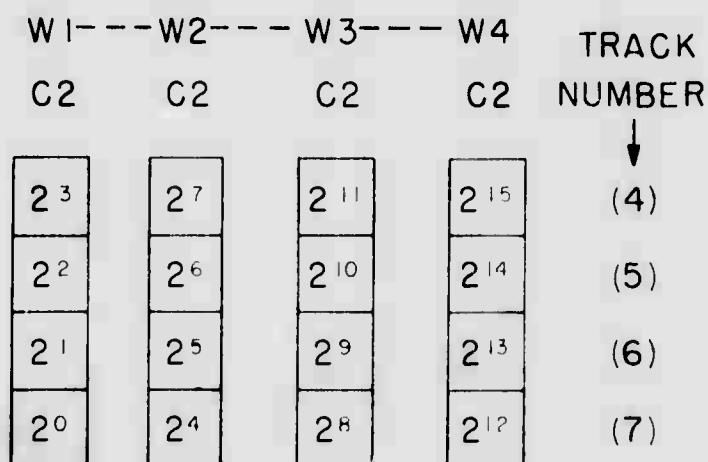


Figure 5.9. Multiplexing Arrangement for Recording Run Time Count

Reference 2 contains a description of a digital depth reference and depth error detector similar to the one designed for this vehicle. Design changes in this latter unit have been made to allow greater latitude in the selection of preset running depths, but the basic technique will remain the same.

Provision is included for recording vehicle water velocity by inputs from a propeller-type speed sensor. The propeller drives a small magnet past a reed relay whose contact closures are counted down for recording in a single bit position in Channel A.

## 5.9 PROFILER

The primary instrumentation focus for the initial arctic vehicle is the under-ice profiler. This unit consists of a wide beam transmitter and a multiple narrow beam receiver array. A multiple beam acoustic transducer-lens system, developed by this Laboratory, will be used for the receiver array. The combined directivity pattern for this array at an operating frequency of 500 kHz and for 15 transducer beams is shown in Figure 5.11. Each beam is associated with a particular transducer of the array and any combination may be selected for recording. The fan-shaped array will be mounted in the vehicle in an upward-looking direction with the plane of the beams perpendicular to the vehicle center line. Only three beams will be implemented for recording at this time.

The profiler transmitter is similar to the one used in the obstacle avoidance sonar, having a pulse width of 200  $\mu$ sec, a peak power output of approximately 100 W, and a pulse repetition rate of five pulses per second, but with an operating frequency of 500 kHz.

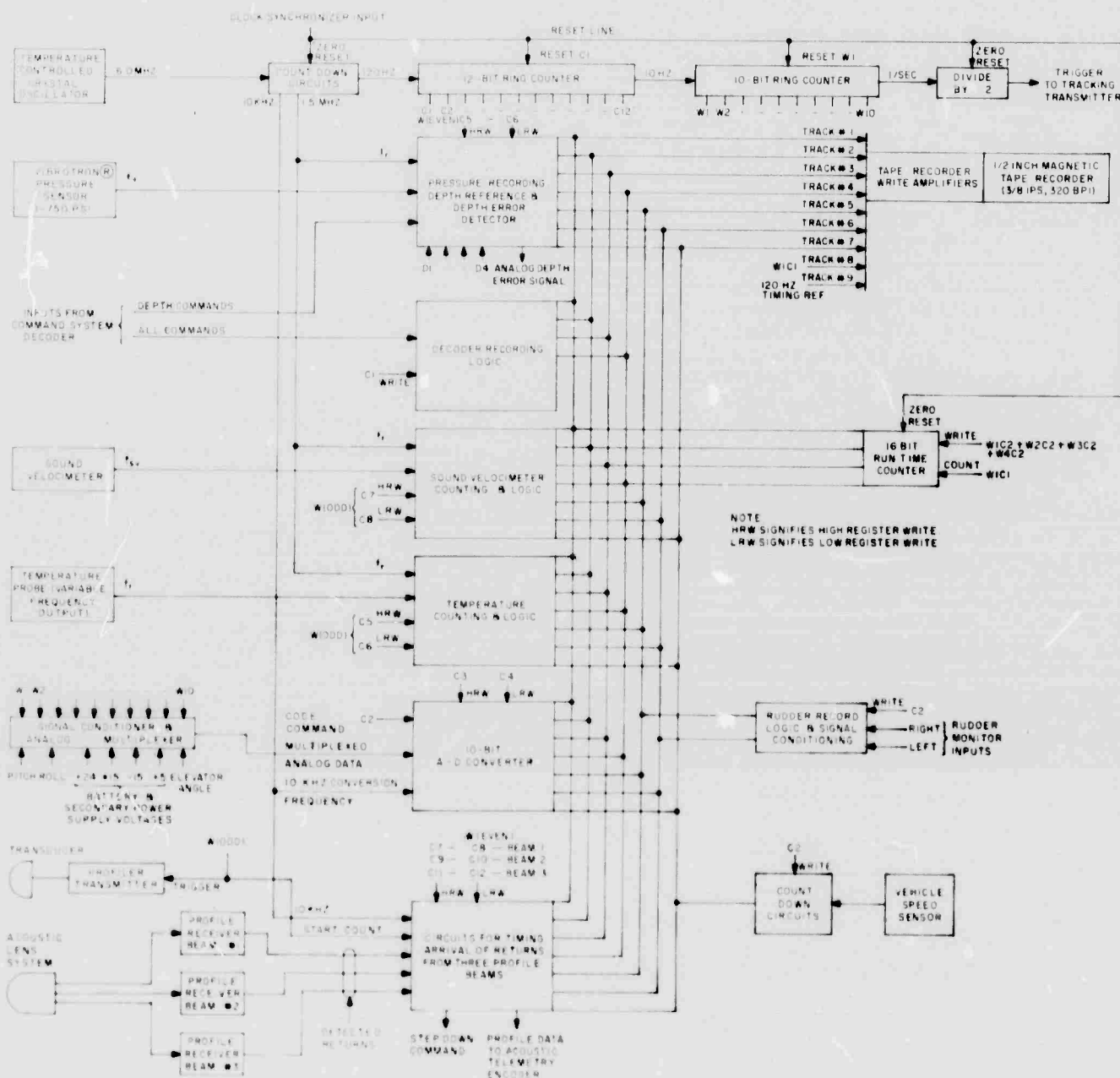


Figure 5.10. Block Diagram of UARS Data System

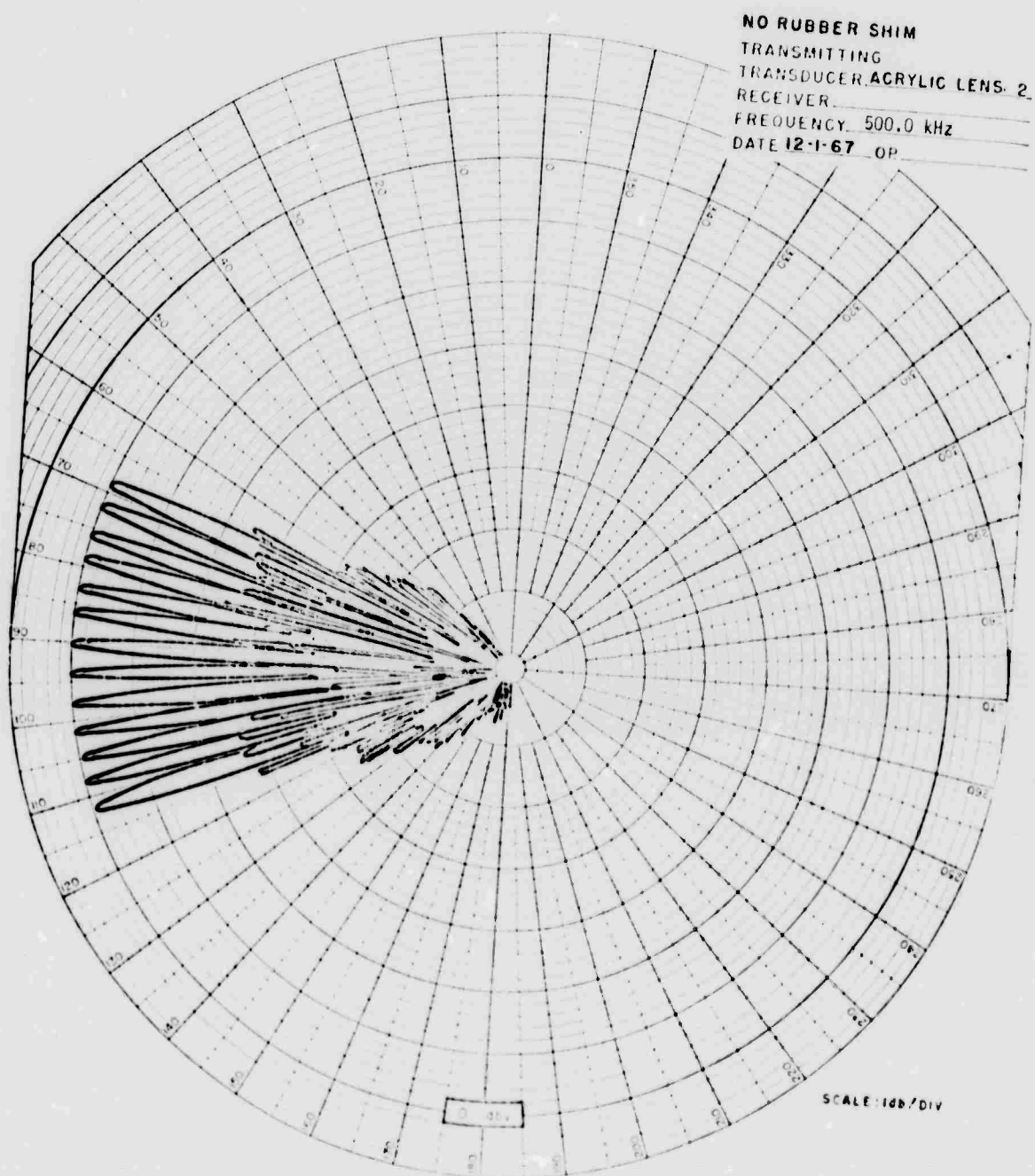


Figure 5.11. Directivity Pattern of Multiple-Beam Transducer-Lens System

Separate, but identical, receivers are used to amplify and detect the returns from the under-ice surface in three beams. The receivers employ a combination of time-varied gain (TVG) and pulse width discrimination to reject false trips from volume reverberation or biological sources. Tests of this system in the Arctic, described in more detail in section 6.3 of this report, indicated that this approach was completely satisfactory, under the ice conditions experienced at ice island T-3 during April of this year. Of particular interest were echo elongation characteristics which show a fundamental distinction between echo returns from fish-sized objects and the ice surface. The 200  $\mu$ sec pulse was returned as an echo of several milliseconds duration, which indicated that significant penetration of the ice was being achieved in spite of the very high frequency employed. The dependence of this behavior upon grazing angle is discussed in section 6.3.

The detected under-ice surface returns from the three profile receivers will be sent to the profile recording circuits which will determine the time of arrival of the returns with respect to the transmitted pulse, and encode it as a 10-bit binary number for recording on the magnetic tape. A block diagram of the profile recording circuits is shown in Figure 5.12.

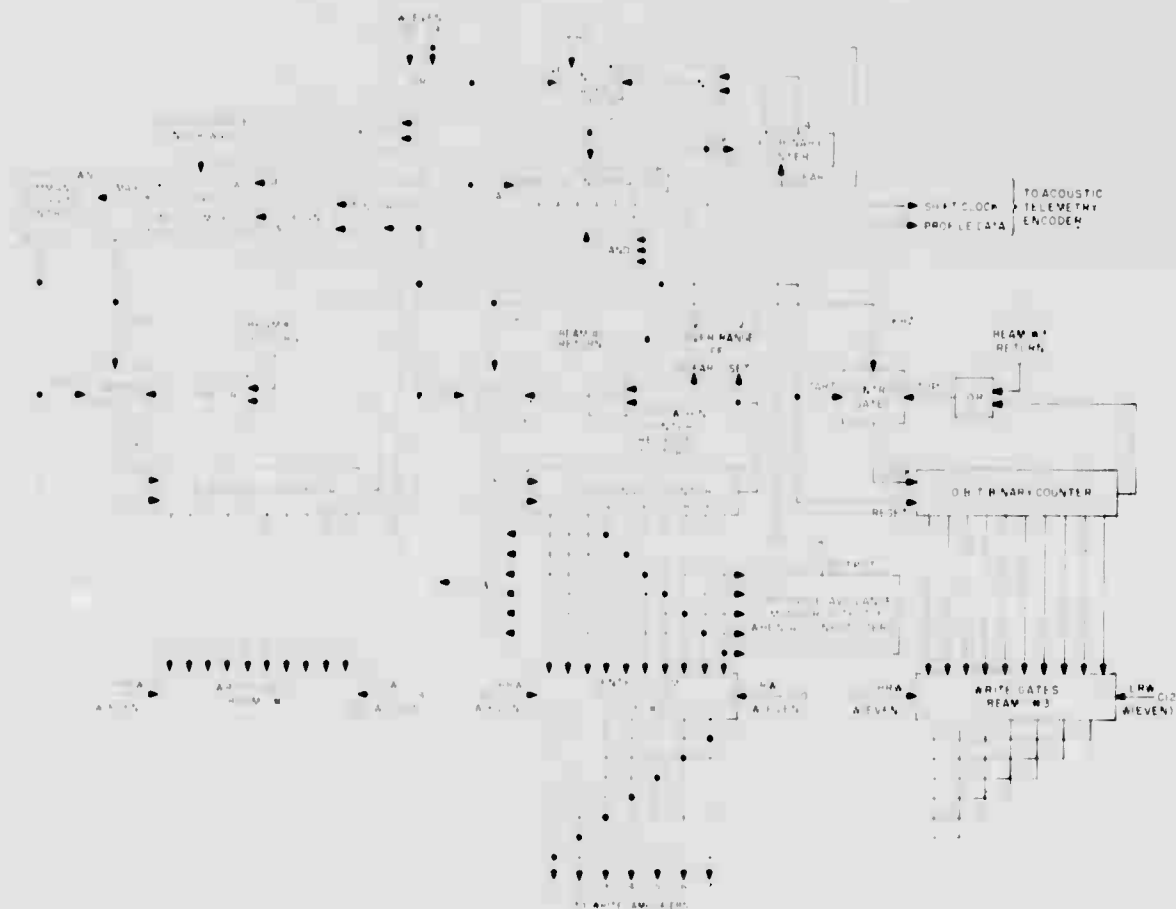


Figure 5.12. Block Diagram of Profiler Recording Circuits



Each beam has a separate 10-bit binary counter which is reset to zero and starts counting at a 10 kHz clock frequency at the start of the transmit pulse. Each counter is stopped at the time of arrival of a return in that particular beam or, in the event of no return, when the counter recycles to zero. At the 10 kHz clock frequency, each bit corresponds to 1/4 ft in range (0.1 msec); the maximum range which can be recorded is 1023 bits or approximately 255 ft. The write pulses (HRW and LRW) for recording the counters occur after the maximum range time but prior to the next transmit pulse.

The obstacle avoidance monitor on the counter for the center beam provides a positive output whenever the number in the counter is less than 32, which corresponds to a range of less than 8 ft. If such a return occurs, an "up" count of 2 is placed in a 4-bit up/down counter by the record pulses C<sub>9</sub> and C<sub>10</sub>. If no return occurs or its range is greater than 8 ft, a single "down" count is entered. Thus, a running count is made of returns occurring at a range of less than 8 ft. If these returns occur more than 30% of the time, the counter will reach a maximum count of 10 and put out a "step down" command to the depth control circuits. It is expected that this would occur only in the event of failure of the obstacle avoidance sonar or if the underside surface of the ice cover has a very shallow slope (increasing in depth) and a very smooth surface so that returns (at the low grazing angle) into the sonar are below the threshold level. An inhibit line prevents further step-down commands from the up/down counter until the previously commanded depth change is completed.

Data from the center beam will also be sent to the acoustic telemetry encoder for transmission (via the tracking pulse) to the tracking site. The data will consist of a 6-bit binary word in which the least significant bit corresponds to a 2-ft range. This data will be used for vehicle navigation purposes which do not require the resolution of the internally recorded data.

#### 5.10 TRACKING TRANSMITTER AND COMMAND RECEIVER

The tracking transmitter and command receiver are discussed together because they function as a two-way acoustic telemetry link between the tracking station and the vehicle. The tracking transmitter, of course, has the separate function of providing an acoustic pulse suitable for tracking the vehicle's position. Both the tracking and command pulses are digitally coded using 100% phase shift keyed modulation at a carrier frequency of 50 kHz with a nominal source strength of 97 dB. Allowing five cycles of the carrier per bit, a 14-bit word can be transmitted within a pulse width of 1.4 msec.

Acoustic tests of this system have been conducted in Puget Sound using the transmitter-receiver depths (approximately 50 and 300 ft) planned for the initial arctic applications. These depths, during the winter test season, were adequate to prevent overlap of the direct and surface reflected pulses. The system demonstrated reliable data telemetry out to the range limits implicit in the developmental model, in excess of 2000 yd. Tests of the same system were conducted under ice in the arctic and similar results were obtained. The arctic tests indicated that higher medium absorption

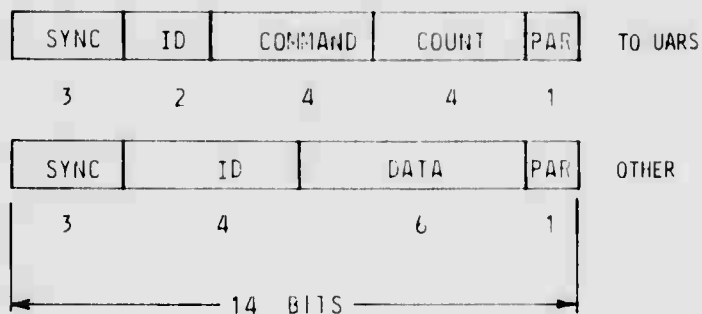
losses, because of lower water temperatures, did not adversely influence the system transient (high frequency) response required to accomplish the phase shift detection necessary in the decoding. The arctic developmental instrumentation also included successful test of an additional code validation feature which requires that the decoded phase of any bit be within  $\pm 45^\circ$  of the proper phase associated with its binary state. This feature, in conjunction with parity checks, gives extremely low probability of an erroneous message being accepted as valid. It does mean, however, that some valid messages will be rejected because of bits failing to meet the phase requirement due to noise, even though they were properly decoded.

A synchronous clock mode of control for the tracking transmitter is used. In this mode, two highly stable clocks, one in the submersible and one at the control processor, are synchronized before vehicle launch. The submersible clock commands transmission at precise times known to both clocks. In order to maintain a tracking accuracy of  $\pm 1$  ft over a run period of 10 hours, a time base stability of  $1 \times 10^{-8}$  is required. Commercial temperature controlled crystal oscillators are available with a frequency stability of  $5 \times 10^{-10}$  over a 24-hour period when held at constant temperature. The variation with temperature is less than  $2 \times 10^{-9}$  over the temperature range from  $-55^\circ\text{C}$  to  $+60^\circ\text{C}$ . Since a stable crystal oscillator and associated count-down circuits are also required in the data recording system, the same oscillator will be used for both purposes.

Tracking pulses will be transmitted from the vehicle at 2-sec intervals, which provides for a 10,000-ft unambiguous tracking range. Because of the large amount of information to be acoustically telemetered to the tracking station, and because of the restriction on pulse length (to avoid multiple path interference), additional coded pulses will be transmitted on the 1-sec mark between tracking pulses. These pulses will be transmitted in response to a command received at the vehicle from the tracking station or when alert codes have been generated internal to the vehicle. In the first instance, only a single pulse will be sent for each command received. However, pulses indicating an alert situation will continue to be sent between tracking pulses until the alert is acknowledged by command from the tracking station. Identity codes will be used to distinguish the various coded pulses transmitted by the vehicle (i.e., tracking, alert, command response) and to identify commands and other coded pulses which may be transmitted to the vehicle or to other objects from the tracking station.

Figure 5.13 shows the pulse coding used for both the tracking and command signals. Table 5.3 lists the vehicle alert situations which are to be transmitted to the tracking site. Since these are independent events, each alert will be indicated by the presence of a "one" in a particular bit position in the data portions of the word with a status 1 identity. A command response at the vehicle will contain a 2-bit code in the data portion of the word indicating the vehicle's acknowledgment of the command as follows:

- 00 command accepted, and acted upon
- 01 parity OK, no redundancy, command stored. (cont. on p. 52)



ID					COMMAND TO UARS
0	0				
0	1	0	0	PROFILER DATA	FROM UARS
0	1	0	1	STATUS 1 (ALERT CODES)	
0	1	1	0	STATUS 2 (HOMING STATUS)	
0	1	1	1	COMMAND RESPONSE	
1	0	0	0	TO BONABUOY	OTHER FIXED REFERENCE
1	0	0	1	FROM BONABUOY	
1	0	1	0	SPARE	
1	0	1	1	SPARE	
1	1	0	0	TRANSDUCER 1	BASELINE AND HYDROPHONE LOCATION
1	1	0	1	TRANSDUCER 2	
1	1	1	0	SPARE	
1	1	1	1	SPARE	

Figure 5.13. Acoustic Communication Binary Code

Table 5.3. Submersible Alert Signals

1. Low Battery Voltage - Main
2. Low Battery Voltage - Reserve
3. Loss of Command - 180° Turn
4. Propulsion Motor Shutoff
5. Obstacle Avoidance from Forward-Looking Sonar
6. Obstacle Avoidance from Profiler

- 10 parity error, command rejected
- 11 busy, still working on last command.

To reduce the false alarm probability in the command link, each command received by the vehicle will be checked for parity and also compared bit by bit with the last received command. For a command to be accepted and acted upon, it must be identical to the last command (including the count portion) and have the correct parity count (i.e., even number of one's in the word). If the parity is correct but the command is not the same as the last, it is not acted upon but stored for later comparison with the following command. Also included in the data portion of the command response will be a 2-bit code indicating the operating depth setting (i.e., D1, D2, D3, or D4) of the vehicle at the time the word is transmitted and a 2-bit count of the false trips registered by the command receiver since the last command response.

A list of commands to be sent to the vehicle is given in Table 5.4. Associated with each step up, down, right, or left command is a 4-bit "count"

Table 5.4. List of Commands to the Vehicle

COMMAND CODE	COMMAND	
0000	Step Right	} On these commands, the number of steps to be taken will be coded in the "count" part of the word.
0001	Step Left	
0010	Step Up	
0011	Step Down	
0100	D1	} Four preset depth commands. These commands will also start propulsion motor.
0101	D2	
0110	D3	
0111	D4	
1000	Start Homing	
1001	Stop Homing	
1010	Alert Acknowledged	
1011	Send Status Data	
1100	Spare	
1101	Spare	
1110	Spare	
1111	Stop Propulsion Motor	

code indicating the desired number of steps. A 4-bit binary number does not allow sufficient incremental  $5^\circ$  steps for a  $180^\circ$  turn which will probably be a fairly common command. A weighting scheme that overcomes this problem will be used. Starting from the most significant bit, the weighting for the 4-bit positions will be 40, 20, 10 and 5 steps with a 0 in all 4-bit positions indicating a single  $5^\circ$  step. This permits, with a single command, large heading changes in multiples of  $15^\circ$  up to a maximum of  $180^\circ$  while still providing for small heading corrections in  $5^\circ$  increments. The magnitude of a single up or down step is adjustable (from approximately 0.1 to 0.64 ft/step). The number of steps per command is coded the same as for heading changes.

#### 5.11 EMERGENCY RECOVERY PINGER

The emergency recovery pinger is mounted in a special housing within the flooded tailcone. The commercial unit selected for this application is self-contained in a cylindrical shape 4 inches long and 1.5 inches in diameter. It is self-activated by immersion in salt water and puts out a few millisecond wide pulse, once or twice a second at a frequency of 37 kHz. Its in-water output signal level (peak value during pulse) is approximately 68 dB (ref. 1  $\mu$ bar at 1 yd) and it has an operating life of 21 days on its internal battery. To increase reception range, a corrosion link release mechanism has been designed to allow the unit to drop from its housing on a tether line (normally coiled in the back of the housing) to a depth of several hundred feet below the vehicle after an immersion period of approximately 14 hours. This link will be replaced before each run. The primary battery power source will also be replaced after each run.

### 6. ARCTIC TESTS OF UARS SUBSYSTEMS

By March of 1971, the design, development, and testing of UARS acoustic subsystems had progressed to the point where tests in the arctic under-ice medium were necessary to resolve questions relating to the physical properties of the transmission medium, the signal return character of the ice undersurface, and effectiveness of subsystem signal processing and validation logic. Tests of hydrohole cutting, thermal coring, and hydrohole heating techniques were also necessary. These tests were conducted during an April field trip to the Naval Arctic Research Laboratory and Fletcher's Ice Island, T-5.

#### 6.1 THERMAL CUTTING OF SEA ICE

The UARS system requires a nominal 4 x 12 ft rectangular hydrohole in the ice for normal vehicle launch and recovery. Holes must also be made for inserting the acoustic transducers (associated with the vehicle tracking, command guidance, and communication system) through the sea ice and a non-destructive technique is required for recovering this instrumentation after it has frozen into the ice. In the event of a system failure wherein the

UARS is unable to return to the recovery hole, the vehicle will eventually come to rest against the ice undersurface where it can be located with the emergency recovery acoustic system. A recovery hole must be made of sufficient diameter to adequately clear the vehicle appendages and to allow diver entry into the water.

Our approach to the problem of hole making involves the use of thermal energy to melt a groove in the ice of the desired core (or frozen-in body) shape. If the groove is cut completely through the ice, the body or core may be removed by lifting. Lifting is, of course, required for recovery of frozen-in objects. If a hole is desired, disposal of the core by pushing it downward through the ice until it tips over and comes to rest on the ice underside is a very efficient technique. Figure 6.1 illustrates the force-displacement relationship for two methods of recovering a solid ice core.

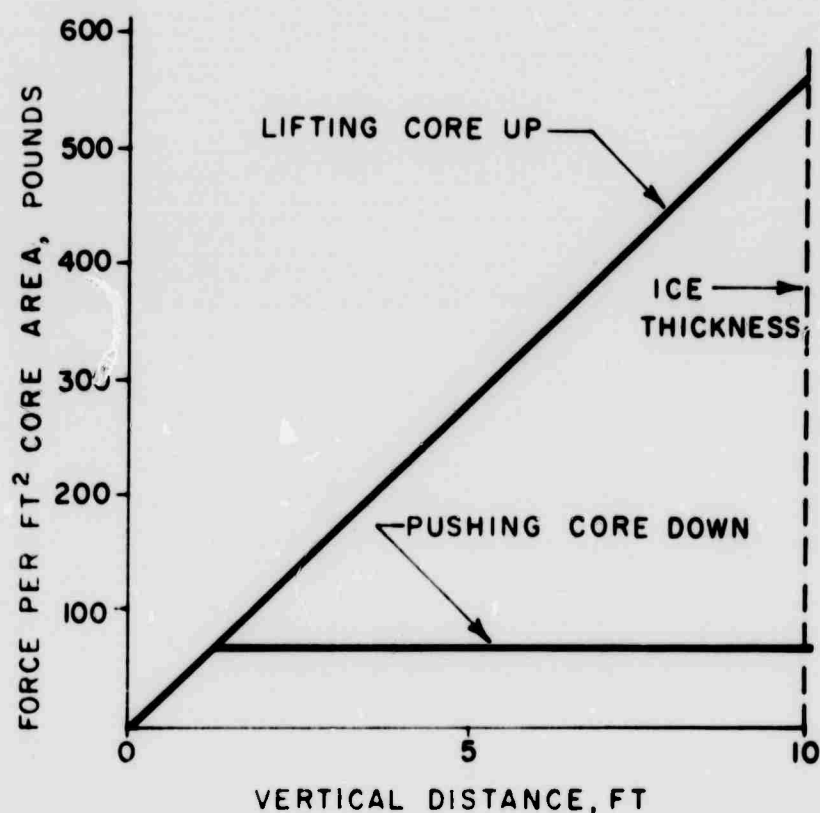


Figure 6.1. Force Comparison of Lifting vs Submerging Ice Core

Pushing the core through the hole bottom requires about  $1/8$  the maximum force and  $1/4$  the energy involved in lifting. Further, a man can "push down" (e.g., climb a ladder-like pole) with a maximum downward force equal to his weight, but his lifting ability is limited to a force of about half his weight. In the case of 10-ft thick ice, to which Figure 6.1 applies, a 200 pound man could dispose of a core whose cross sectional area is about 5 square feet.

The technique employed to melt the desired groove shape employs heat transfer from warmed water in direct contact with sea ice to cause melting in a shape or core determined by the distribution manifold for the delivered water. The melt water is recovered by a suction intake which is mounted directly above the delivery manifold. The excess melt water is discarded and heat is supplied to the remaining water which is recirculated. It is very desirable to keep the groove "dry" in that unnecessary heat transfer to the groove sides is prevented and since no water contacts the groove sides above the suction intake, refreezing of the core to the ice is impossible. The object of the experiments was to verify the feasibility of this approach in the arctic environment and to determine the configuration of delivery port placement, flow rates, and suction intake elevation for optimum vertical cutting speed and groove width.

The experimental apparatus consisted of a pan with vertical tubular vents, sized to fit over a three burner Coleman gasoline stove which had been modified to mount three generator systems (equivalent heat output of three stoves of this type) which transferred approximately 25,000 Btu per hour to the working fluid. These generator-burner assemblies were coupled to a fuel tank made from a 5 gallon fire extinguisher bottle. A pair of small electric motor-driven pumps (approximately 2 gallons per minute capacity at 5 foot head) were used to supply heated water through a delivery hose to the cutting head and for returning working fluid to the heating pan by means of an intake base. The heat source, pan and pump system were mounted in an insulated open top box and arranged in such a manner that snow could be melted for startup and that waste heat during this period would warm up the motor-pumps. The hoses were natural rubber with an insulation system of "space blanket" material covered with a protective, waterproof plastic sheath. An electric heating cable was wound directly on the hoses under the insulation system so that the hoses could be thawed if frozen.

The maximum heat transfer rate obtainable with the experimental system was 25,000 Btu per hour which is equivalent to the energy requirements for melting about 2.5 cubic feet of  $0^{\circ}\text{F}$  sea ice and discharging  $60^{\circ}\text{F}$  melt water.

Our first experiment at Barrow utilized a 10-inch square cutting head (made of 1-inch diameter electrical conduit) with 48 exit holes, of 0.062 inch diameter, equally spaced on the lower side. A 1/2-inch diameter suction nozzle was mounted above the cutting head on the side opposite the delivery hose port. The apparatus was set up in the middle of the salt water lagoon adjacent to the Naval Arctic Research Laboratory. The snow to start the system was melted and brought to  $160^{\circ}\text{F}$  in about 30 minutes. Cutting was started and a 4-foot long core was removed 45 minutes later. Figures 6.2 and 6.3 illustrate the cutting process and the equipment setup (after breakthrough). The width of the cut was about  $1-7/8$  in. for the first 6 inches.



Figure 6.2. Ice Coring



Figure 6.3. Ice Cutting Equipment



At this depth, the hot water in the tank at the start of cutting was depleted and steady state heat transfer conditions were achieved. The width of cut below 6 inches was excessive (greater than 4 inches). During the steady state operation of this test, the temperature difference between suction and delivery was 22°F with 72°F water delivered. The water level was kept well above the suction intake (by varying pump speed) at all times.

Further tests indicated the desirability of keeping the water level as low as possible in the hole, restricting the water flow to obtain the highest delivery temperature consistent with the largest temperature difference. On 8 April the system was set up on the sea ice west of the NARI runway. A 12-inch square cutting head was used with the suction pump operating at maximum capacity and delivery pump flow rate reduced so that large amounts of air were ingested. Setup and snow melting consumed about 1/2 hour, and 95 minutes later a core 63 x 9-1/2 inches square was removed, leaving a 15-3/4 inch square hole in the ice. The core could easily have been pushed down but it was removed for inspection.

At T-3, a hole about 15 inches square was made in 15-1/4 feet of sea ice (Colby Bay) in 6-1/2 hours. The core had 47 pounds of buoyancy and was easily pushed through the hole bottom to leave a clear working hole which was subsequently used in acoustic experiments (described later in this section). During the cutting process, the core was severely eroded by water circulation toward the single point of suction intake. This problem was alleviated by mounting an intake manifold similar to the cutting manifold directly above the latter, allowing approximately 1/4 inch clearance between the two tubes. A square cutting head so modified and a linear cutting bar 3-1/2 feet long were fabricated from conduit at T-3 and used to cut the bottom out of a conventionally excavated hydrohole. This 4 x 4-foot hole had been dug to a depth of 19-1/2 feet. The final 1-1/2 feet to the sea were cut with some boot-strapping of the suction return line. The lift required from the hole bottom to the level of the suction pump was about 22 feet, which was beyond the pump capacity. It was necessary to place another pump in series with the suction hose and suspend it a few feet above the hole bottom. On breakthrough, this motor-pump was rapidly hoisted to clear the incoming water. The linear cutter bar was used to cut the sides of the block between holes made in the corners by the modified square cutting head.

The experimental system performed closely to the theoretical limits implicit in the thermodynamic principle involved. The "dry hole" approach proved effective even though operations were accomplished with ice and ambient temperatures (at the surface) as low as -27°F (15-1/4 foot hole test). During all of the tests, the rather trivial heat source cut a 2-inch wide slot whose length-depth product exceeded 10 feet square per hour. To melt and discharge this volume of sea ice required a minimum energy of about 16,000 Btu per hour. The energy input of the gasoline heater to the working fluid was never more than 25,000 Btu per hour, and was estimated to be somewhat less than 20,000 Btu per hour during most of these tests due to fouling of two generators. A design utilizing propane as a fuel source and having an energy output about six times greater than the experimental device is being prepared. The heater and associated pump equipment will be contained in

roughly a 30-inch cube and weigh about 300 pounds. Such a system should melt a 2-inch groove whose length-depth product is in excess of 50 feet square per hour. A 4-foot square by 20-ft deep hydrohole, with the core cut into four square columns, could be made with such a device in about 5 hours. The force required to push out the individual ice columns would be about 500 lb.

## 6.2 HYDROHOLE MAINTENANCE

Tests were conducted to determine whether the experimental ice thermal cutting system described above might be suitable for preventing hydrohole freezeup. During operations with UARS in the central Arctic, it is estimated that the equivalent of 2 kW of electric power would be required to keep the 4 x 12 foot hydrohole dimensionally stable. Heating hydroholes by electrical means with a power-distribution system such as at T-3 utilizes only about 12% maximum of the thermal energy available in the fuel. Direct use of the fuel source should be from five to seven times more efficient.

The experimental heat source for the thermal cutting experiment was used at minimum power level (equivalent to about 1 kW) which was more than sufficient to maintain hole size in the 15-inch square hydrohole. During this test, water was simply recirculated from the hydrohole to the heater and back, through the pair of hoses. A similar experiment was tried in a larger hydrohole at T-5,, using a circulating pump and hoses connected to a heat exchanger made from a 50-foot coil of 1/2-inch copper tubing. The makeshift heat exchanger transferred heat to the water from the room air near the heating stove at better than 5000 Btu per hour (1.5 kW) rate. We propose to use this approach to keep the UARS hydrohole open since the room furnace is reasonably efficient at utilizing the fuel energy (perhaps 65-70%) and the electric pump power is less than 200 W. An example of fuel saving possibilities for conventional hydroholes based on a year around average hole heating maintenance budget of 1 kW electrical power is revealing. Consider a diesel generating plant with diesel operation at 0.6 lb of fuel per horsepower hour, a generator efficiency of 70%, a transmission line efficiency of 75%, a hot air furnace efficiency of 65% and an average circulating pump power of 40 W. The annual net fuel saved by this technique would be 26 barrels per hydrohole based on an average 1 kW heat demand.

## 6.3 ACOUSTIC SYSTEMS TESTS

### 6.3.1 TRACKING AND COMMUNICATION SYSTEM

This system utilizes digital instructions, phase modulated on a 50 kHz carrier pulse, to convey guidance instructions to UARS and obtain return verification of acceptance, compliance, and execution of the instructions. The return verification is transmitted from the UARS at previously synchronized times so that range/range tracking information is also carried by the pulse from UARS. This same pulse is used to transmit selected data in near real time for use in experiment control.

The expected range of this system, at the signal levels employed, was 1 nautical mile. The prototype system was tested, using 1.2 msec pulses which carried 12 bits of information and transmitted at the rate of 2 pulses per second, from a sea-ice station outside Colby Bay, a distance in excess of 1 mile from the base hydrohole. It was determined that the prototype design was successful and that the information transmitted could be recognized, decoded, and displayed with sufficient redundancy in the validation logic that errors were essentially eliminated. Errors can come from near-ice echoes, in-water pulse deterioration, multipath interference, or insufficient signal-to-noise ratio. Unfortunately, an intermittent I-C failure in a ring-counter circuit of the code transmitter limited the test time that the preset code was correctly transmitted. However, in all cases, the receiver rejected as invalid all spurious transmissions. The tests indicated that, to a distance somewhat more than 1 mile, tracking and guidance would be adequate, despite the presence of the ice-water interface, where total water depth is 600 ft or greater.

The applicability of this system to 200-foot water depths such as those encountered in the marginal ice zone will be investigated during MIZ experiments scheduled for August 1971.

#### 6.3.2 OBSTACLE AVOIDANCE AND UNDER-ICE PROFILING

These systems have much in common, since both scan the undersurface of the ice.

The avoidance system operates at 560 kHz, looks directly forward with a narrow beam, and is intended to alert the UARS to ice keels. The profiling system operates at 500 kHz and looks directly upward with a raster of narrow beams to obtain detailed information on the under-ice profile. Both systems require that the pulse size, shape, and frequency be appropriate to a precise and reproducible determination of the water-ice interface. The tests included a slow scan of the under-ice surface by each system, from vertical to horizontal, in several directions as illustrated in Figure 6.4. No change in design approach or logic was indicated.

One of the logic requirements for both the profiler and obstacle avoidance is that the pulse reflected off the ice be distinguished from small scatterers in the medium. For example, the echo (or reverberation) pulse length from a single fish is related to the size of its abdominal cavity, while the reverberation pulse length from the ice is a function of the sonar beam width, the grazing angle, and backscatter strength of the surface. The UARS obstacle avoidance and profiler beams are very narrow and side lobes are well suppressed. Backscatter tests for both systems were made to verify the adequacy of the design.

Figure 6.5 illustrates a typical reverberation pulse length measurement as a function of nominal grazing angle with the ice undersurface. In this example, a 200  $\mu$ sec, 110 dB pulse was transmitted from a very narrow ( $4^\circ$  beam width) transducer whose side lobe suppression was greater than 50 dB. The transducer was suspended 40 ft below the ice undersurface. The pulse length is taken to be the continuous time during the reverberation return

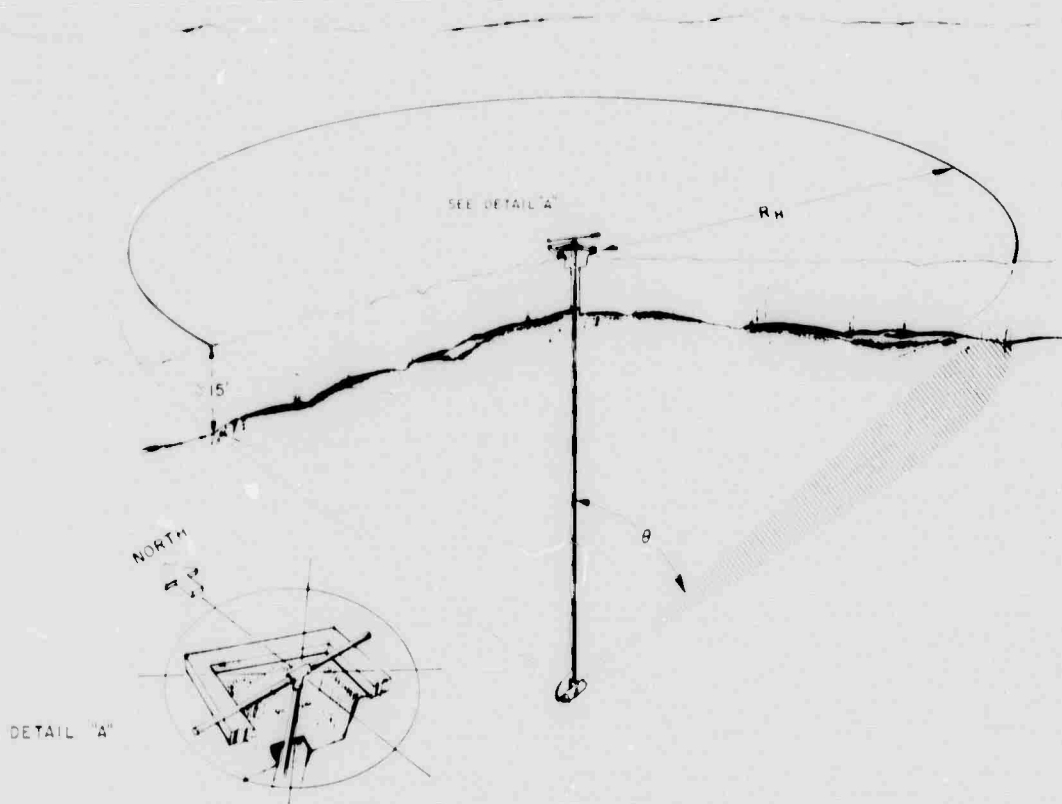


Figure 6.4. Variable Grazing Angle Acoustic Test Arrangement

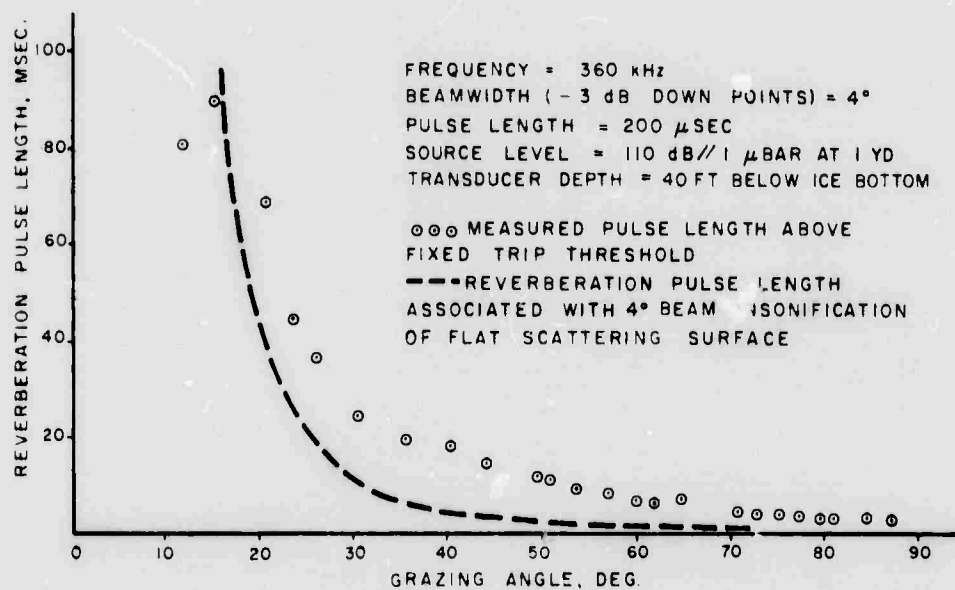


Figure 6.5. Typical Reverberation Pulse Length Measurement as a Function of Nominal Grazing Angle with the Ice Undersurface

that the signal exceeds a trip threshold set approximately 20 dB above system noise. The dashed curve indicates the length of reverberation pulse that would be expected based upon transducer directivity and grazing angle with a flat (but rough) reflecting surface.

The transducer support structure interfered with measurements near the  $90^\circ$  grazing angle (normal incidence). However, it can be seen that the reverberation pulse lengths, defined as above, are, in all measured cases, greater than 2 msec, which represents the return from an object about 4 ft long. This satisfies the validation requirements (pulse length, 1 msec) implemented in the design.

The roughness of the surface was sufficient to give adequate backscatter signal out to a range in excess of 500 ft, even at a grazing angle very close to  $0^\circ$ .

The individual reverberation signals at less than the critical angle of incidence (approximately  $30^\circ$ ) showed consistent evidence of signal penetration to the air-ice surface. Unfortunately, the dynamic range of the receiver/recording system was not great enough to allow the complete envelope of both pulses to be preserved.

#### 6.3.3 HOMING SYSTEM

This system, operating at 28 kHz, is intended to return the UARS to the launching hole for recovery. It requires the execution of two functions which merge at some intermediate range.

The long range function, for attracting the vehicle from a distance of 2-3 miles, must reach beyond the range of the tracking and communication system. At this long range, a highly precise aim toward the recovery hole is not necessarily required, and the logic requirements for signal detection and reacquisition search in the event of signal loss are quite different from those for short range. At short range, the same homing electronics must precisely and automatically guide the UARS into the recovery net beneath the launch/retrieval hydrohole, and, in case of a miss, the vehicle must quickly recognize this fact and immediately begin reacquisition search for the target beacon in the capture net.

The tests utilized four locations, 400, 6500, 11,000 and about 15,000 ft from the base camp hydrohole.

The bearing measuring transducers were mounted on a pipe suspended 50 ft below the bottom of the ice. The pipe was rotated to train the transducers in the desired direction. The applicability of CW transmission to the short range control function was first tested, with updating of homing control about 10 times per second. A strong and stationary acoustic standing wave pattern existed immediately below the ice in the near field (within a radius of a few hundred feet) of the homing beacon. This gave ambiguous bearing information except where the homing receiver hydrophones included the homing beacon within a quadrant  $\pm 45^\circ$  from the  $0^\circ$  relative bearing axis. Outside of this sector, moreover, the rate of change of the indicated bearing was several times greater than the rotational rate of the training mechanism.

Pulsed transmission tests, with the beacon and receiver at depths where direct and reflected pulse overlap could not occur, were conducted at the 6500, 15,000 and 11,000-foot ranges. The first test at 6500-foot range gave excellent results. Reflected pulses from the near vertical wall of the ice island at its junction with Colby Bay were, in some instances, sensed as true beacon targets, since on an individual pulse basis, they met the frequency, pulse length, amplitude criteria of the prototype system. Small changes in depth of the receiving hydrophones caused large changes in apparent target bearing on these false signals. The beacon was moved to 15,000-foot range but was not detected by the homing system. The beacon was brought into closer range, about 11,000 feet, where an open lead was found. The reception was satisfactory and the results were similar to that obtained at the 6500-foot range. The beacon source level was 94 dB (ref 1  $\mu$ bar at 1 yd); 4-msec pulses were transmitted at a rate of two pulses per second. The received signal was observed to have a level of -2 dB re 1  $\mu$ bar. This indicates an absorption loss of 6 dB per kyd which was slightly higher than expected. During the Puget Sound tests, the absorption losses were about 1.5 dB per kyd less because of the higher water temperature, which accounts for the difference in maximum working range at the two locations.

These tests indicated the necessity of utilizing pulse transmission to avoid the standing wave problem. The output of the steering hydrophones was recorded during these tests so it became possible to test, in the Laboratory, different types of validation logic based upon the homing geometry with actual under-ice transmitted signals. The present homing system design described in section 5.7 reflects this approach.

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**SURFACE EFFECT VEHICLES FOR ARCTIC PERSONNEL**

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### **Summary**

In this report are presented analyses of potential Arctic scientific Surface Effect Vehicle (SEV) missions, available engineering design data, Arctic SEV test experience and preliminary design specifications for two typical scientific mission profiles in the Arctic. From analysis of scientist response to SEV utility for their investigations, it became apparent that a) scientists would use any machine in which they had confidence; b) no clearly defined research projects could be identified requiring high-speed travel over large distances on the ice pack; c) the effects of the vehicle's own environment on potential experiments to be carried out using the vehicle as a mobile platform are completely unknown; and d) many scientists felt that their immediate goals did not justify the expense involved in developing an Arctic SEV solely for research missions. The current state-of-the-art engineering data available for design of new vehicles for the Arctic environment was reviewed. Severe deficiencies exist in actual flight test verification of theoretical design curves for performance analysis; evaluation of data available on Arctic SEV operations indicate a degradation of speed and range capability to 50% of theoretical predictions. The lack of specific engineering design data feedback available for future designs leads to a set of recommended flight tests which are considered to be the vital link in developing new concepts and technology for Arctic vehicles. To aid in the technology evaluation two typical potential scientific mission profiles were utilized to develop

preliminary SEV designs. These preliminary designs served chiefly to focus the principal problem areas involved in developing Arctic SEV's.

### Introduction

The principal goals of the Surface Effect Vehicle mission and technology study phase of ARPA Contract No. N00014-67-A-0103-0016, antititled, "Advanced Arctic Technology," were a) a well-defined set of mission specifications as determined by specific Arctic scientific missions; b) critical problem areas in SEV technology as defined by the mission and environmental constraints, and c) explicit problem statements and research proposals for their resolution. During the course of this study, emphasis on these goals shifted as information was acquired; the rationale of the study and the focus of effort will be outlined in this section with specifics of the study contained in later sections.

#### 1. SCIENTIFIC MISSIONS

In order to compile a set of scientific mission profiles, scientists were approached with requests for their specific mobility and load needs. Unfortunately, scientists do not visualize their missions in logistics terms, as is necessary for vehicle mission specifications. At the time of this study many scientists had their attention focused on the AIDJEX Program (Arctic Ice Dynamics Joint Experiment - Ref. 1). This mission appears to be representative of the needs of a majority of current research needs and hence was chosen for one preliminary design study. A second class of missions falls into the general supply category, hence leading to the Arctic freighter concept, the

other preliminary design study presented in this report. Since large supply operations in the Arctic have been carried out to date with C-130 aircraft, most load requirements were related to C-130 capabilities.

The following general conclusions emerged during this early mission specification study: a) scientists would use any machine in which they had confidence; b) few clearly defined research projects could be identified requiring high-speed travel over large distances on the ice pack; and c) many scientists felt that their immediate goals did not justify the expense involved in developing an SEV solely for research missions. Reservations about the unknown effects of the vehicle's own environment on potential experiments to be carried out using the vehicle as a mobile platform were expressed. Since a majority of scientists approached on this problem had considerable Arctic experience, the importance of simplicity, reliability, safety and all-weather operational capability was repeatedly stressed. It was felt that an Arctic research team with minimum supporting personnel and facilities could not depend on any vehicle in the developmental stages due to the hazards of the environment.

In conclusion, it is noted that almost any large-scale, high-speed scientific mission envisioned could be considered in the same class as any of the military missions previously proposed. A rather extensive list of such missions has been already compiled through previous studies.

In order to identify the critical technology areas in Arctic research SEV development, it was decided to carry out preliminary designs on the two typical vehicles identified for the AIDJEX mission and for Arctic scientific

logistics. Parallel to this study, an evaluation of the operational experience with SEV's in the Arctic was undertaken. This approach was chosen since literature study and critical examination of the "Recommendations for an Arctic Research Program in Support of the Design of a Surface Effect Vehicle System" submitted to ARPA by the Arctic Institute of North America gave no indication that "flight test" data (as distinct from operational test data) has been acquired during the Arctic tests to date. In order that development of new and novel approaches to transportation in the Arctic proceed on a sound basis, the actual engineering flight performance of existing machines must be measured and evaluated and these evaluations related to design performance. Furthermore, from reported test results, it is not clear whether current SEV's are suited for Arctic operations; moreover, the critical limitations in range and velocity and their relationship to vehicle size have not been rigorously identified. Therefore, it is the contention of this report that a comprehensive flight test program designed to provide engineering data feedback on existing machines is of primary importance at this time. Conversely, at this time, it appears that specific technological problem areas, i.e., skirt materials, navigation, maneuverability, etc., are not as critical as the determination of actual capabilities and how theoretical performance is degraded by the Arctic environment.

In the following sections of this report, the two preliminary design studies are presented. These studies were conducted primarily by two senior students, Mr. Lawrence Pearson and Mr. James M. Young, in a design class in

the department of Aeronautics and Astronautics. Since the primary purpose of these designs was to identify the shortcomings of available design information, (and not to achieve complete preliminary designs) the results are necessarily brief. The results are presented to aid the reader in visualizing the design process to which the recommended tests described later apply.

## 2. PRELIMINARY DESIGN STUDIES

Two vehicles were considered, one of which was to support the AIDJEX (Arctic Ice Dynamics Joint Experiment) program as defined in Reference 1, and the other (called the Arctic Scientific Logistics SEV) which was sized to support a more extensive effort at a larger distance from home base. The specifications used in this study for these two vehicles were as follows:

### 2.1 Specifications

#### 2.1.1. Specifications for the AIDJEX SEV.

Range, max.	1,000 statute miles
Payload	6,000 pounds
Design speed	30 miles per hour
Maximum grade	10%
Skirt height	4 ft

#### 2.1.2. Specifications for the Logistics SEV.

Range, max	2,000 statute miles
Payload	21,000 pounds
Design speed	50 miles per hour
Maximum grade	10%
Skirt height	8 ft

Originally, the range of the larger vehicle was set at 2,000 nautical miles plus reserves, but, as will be discussed later, this range was arbitrarily reduced in light of the requirements.

The speeds and area loadings were kept rather low for several reasons, among them that past experience has shown that high speed over the Arctic terrain is difficult to maintain, as it was felt that the large air velocities associated with large plenum pressures might bring problems of snow blowing, erosion, etc. Therefore, a maximum plenum pressure of about 50 lb/ft<sup>2</sup> was set.

## 2.2. Results of the Preliminary Design Study

### 2.2.1. Inputs and Assumptions

Following are the inputs and assumptions that were introduced into the performance equations. In defining these and in succeeding sections, the following nomenclature will be used:

$W_0$	Gross weight, lb
$W_1$	Gross weight less fuel weight, lb
$W_E$	Empty weight, lb
$W_{PL}$	Payload weight, lb
$b$	Beam, ft
$l$	length, ft
$S$	Base area of plenum, sq. ft. (taken to be $bl$ in this report)
$C$	Circumference of plenum (taken to be $2(b + l)$ in this report)
$A$	Frontal area, used as reference area for aerodynamic drag



$h$	Height of bottom of skirt above ground, ft
$v_o$	Speed of SEV through air, ft/sec
$V_o$	Speed of SEV through air, statute mph
$v_j$	Velocity of air emerging from plenum, ft/sec
$D$	Discharge coefficient for air emerging from plenum
$P_o$	Ambient air pressure, lb/ft <sup>2</sup>
$\rho_o$	Mass Density of ambient air, slugs/ft <sup>3</sup>
$q_o = \frac{\rho_o v_o^2}{2}$	Dynamic pressure, lb/ft
$P_c$	Cushion pressure, gage above ambient pressure $P_o$ , lb/ft <sup>2</sup>
$P_t$	Total pressure, static pressure plus dynamic pressure, lb/ft <sup>2</sup>
$\eta_R$	Ram efficiency, defined by - Total Pressure ahead of lift fan $= P_o + \eta_R q_o$
$\eta_D$	Direct efficiency, defined by - Cushion total pressure $= \eta_D$ (Total pressure behind lift fan)
$\eta_P$	Propulsive efficiency (of lift fans or thrust propellers)
$C_D = \frac{D}{q_o A}$	Drag coefficient
$c'$	Specific fuel consumption, lb. of fuel per hour/horsepower
$\mu N$	Friction force of skirts on surface, lb.

Referring to the above list of symbols, the inputs and assumptions used to calculate range were:

$\frac{W_E}{W_o}$	= 0.6 for all machines
$W_{PL}$	= 6000 lb for small machine = 21,000 lb for large machine

Plan form - rectangular of  $l = 2b$ , so

$$S = 2b^2$$

$$C = 6b$$

$$\text{Height} = \frac{b}{2} \text{ so}$$

$$A = \frac{b^2}{2}$$

$$\frac{h}{b} = 0.01 \left( \frac{h}{b} = 0.01, 0.008, \text{ and } 0.005 \text{ used in study} \right)$$

$$V_o = 30 \text{ mph for small machine}$$

$$= 50 \text{ mph for large machine}$$

$$D = 0.5$$

$$P_o = 2116 \text{ lb/ft}^2 \text{ (standard sea level)}$$

$$\rho_o = .002378 \text{ slugs/ft}^3 \text{ (standard sea level)}$$

$$C_D = 0.35$$

$$c' = 0.5 \text{ lb of fuel per hour/horsepower}$$

$$\mu_N = 0$$

$$\eta_R = 0 \text{ } (\eta_R = 0 \text{ and } 1 \text{ used in study})$$

$$\eta_D = 0.98 \text{ } (\eta_D = 0.98 \text{ and } 1 \text{ used in study})$$

$$\eta_P = 0.70 \text{ } (\eta_P = .7 \text{ and } 1 \text{ used in study})$$

#### 2.2.2. Results

Results are in two categories; first are the vehicles resulting from the preliminary design study, and second are the results of studies when some of the design parameters were varied to obtain trends.

The smaller or AIDJEX machine has the following dimensions and weights:

Length                      37 ft

Width                        20 ft

Height 17 1/4 ft

Skirt height 4 ft

Cabin dimensions

length 15 ft

width 10 ft

height 7 ft

floor area 139 sq ft

Gross weight 28,600 lb

Empty weight 17,200 lb

Fuel weight 5,400 lb

Payload weight 6,000 lb

Base area 596 sq ft

Frontal area 200 sq ft  
(skirt inflated)

Cushion pressure 48 lb/ft<sup>2</sup>

Lift fan diameter 4 ft

Propeller diameter 8.5 ft

Horsepower 826

Cruise speed 30 MPH

Maximum grade 10%

Range 1,000 miles

The larger or logistic SEV has the following characteristics:

Length 79 ft

Width 39 ft

Height 36 ft

Skirt height 8 ft

Gross Weight 145,000 lb

Empty Weight 87,000 lb

Fuel Weight 37,000 lb

Payload Weight 21,000 lb

Base area 3,000 sq ft

Cushion pressure 48 lb/ft<sup>2</sup>

Lift fan diameter 7.5 ft

Propeller diameter 8 ft

Horsepower

Lift 2 engines at 1200 HP each

Propulsion: 2 engines at 1640 HP each

Cruise speed 50 MPH

Maximum grade 10%

Range 2,000 miles

Other results are presented in figures 1 to 3.\* These figures show results for rather low base loadings. Figure 1 shows the variation of optimum velocity with base loading as various of the efficiencies are varied. Figure 2 shows the range at optimum velocity as functions of these same variables as well as with height above the surface. Figure 3 shows the variation of gross weight with range for vehicles carrying 6,000 lb payloads at 30 MPH and 21,000 lb payloads at 50 MPH.

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\* the figures appear on pages 24 - 28

### 2.3 Discussion

The items which were felt to be of primary importance in the consideration of SEV's for Arctic work were range, speed, and cushion pressure. The range was dictated by the mission. The velocities were arbitrarily chosen rather low as experience has shown that it is difficult to maintain high speed over much of the Arctic terrain especially with a small machine. Therefore the range was optimized around velocities of 30 MPH for the smaller machine, and 50 MPH for the larger machine. The cushion pressures were arbitrarily kept below 50 lb/ft<sup>2</sup> because of lack of information as to the pressures capable of being supported by the snow fields and ice packs in the Arctic. It is possible that even these pressures are too high.

With these choices made, the range equation was developed under the following assumptions:

- 1) The machine stays close enough to the ground that it can be considered a plenum machine.
- 2) The power required to sustain or lift the machine is independent of forward speed at the rather low speeds used in this study.
- 3) The aerodynamic lift is zero.
- 4) The surface over which the machine operates is smooth and level.
- 5) Propulsive efficiencies of lift and propulsive fans are equal.

With these assumptions, and using the nomenclature on page 5, the range equation below may be developed.

$$\begin{aligned} \text{Total Power} = & \text{Lift Power} + \text{Power due to Ram Drag} + \\ & \text{Power due to Aerodynamics Drag} + \\ & \text{Power due to Contact Friction.} \end{aligned}$$

The following equations were used for these various terms:

$$\text{Lift Horsepower} = \frac{Dh C \sqrt{\frac{2}{\rho_o} p_c} \left[ p_o \left( \frac{1}{\eta_o} - 1 \right) + \frac{p_c}{\eta_o} - \eta_a \left( \frac{\rho_o}{2} v_o^2 \right) \right]}{550 \eta_p}$$

$$\text{Ram Drag Horsepower} = \frac{Dh C \rho_o v_o^2 \sqrt{\frac{2}{\rho_o} p_c}}{550 \eta_p}$$

$$\text{Aerodynamic Drag Horsepower} = \frac{C_D A (\rho_o / 2) v_o^3}{550 \eta_p}$$

$$\text{Friction Horsepower} = \frac{\mu N v_o}{550 \eta_p}$$

In the above equations, since aerodynamic lift is considered to be zero, the lift, which is equal to weight is

$$W = p_c S$$

and thus  $p_c$  may be replaced by  $\frac{W}{S}$ .

The fuel used is

$$\text{Pounds of fuel/hour} = (\text{Horsepower}) c' = -\frac{dw}{dt}$$

$$\text{or } dt = \frac{-dW}{(\text{Horsepower}) c'} \quad \text{hours}$$

The range is

$$R = \int_{W_0}^{W_1} V_0 dt \quad \text{miles if } V_0 \text{ is miles/hour and } dt \text{ is hours}$$

$$= \int_{W_1}^{W_0} \frac{V_0 dW}{(HP) C'}$$

Combining the above terms, one gets for the Range equation, changing weight variable to  $\frac{W}{S}$

$$R = 550 \int_{\frac{W_1}{S}}^{\frac{W_0}{S}} \frac{V_0}{C'} \frac{d\left(\frac{W}{S}\right)}{\left\{ \frac{DhC \sqrt{\frac{2}{\rho}} \frac{W}{S} \left[ p_0 \left( \frac{1}{\eta_0} - 1 \right) + \frac{W}{S \eta_0} - \eta_R \left( \frac{\rho_0}{2} v_0^2 \right) \right] + DhC \rho_0 v_0^2 \sqrt{\frac{2W}{\rho S}} + C_D A \frac{\rho_0}{2} v_0^3 + \mu N v_0 \right\}} \right.}$$

$\eta_P$

The inputs listed on pages 6-8 were used in this equation and the equation integrated to give basic plots. It is to be noted that the range was obtained for various values of  $\frac{W_1}{W_0}$ , since from this value it is easy to obtain the weight of the machine needed for a certain range if the payload is known, since

$$W_1 = W_E + W_{PL}$$

Using the assumption that  $\frac{W_E}{W_0}$  is independent of the size of the machine, and only a function of the state of the art (and thus time)

$$\frac{W_1}{W_0} = \frac{W_E}{W_0} + \frac{W_{PL}}{W_0}$$

$$W_o = \frac{W_{PL}}{\left( \frac{W_i}{W_o} - \frac{W_E}{W_o} \right)}$$

Thus, to get range one may pick the value of  $\frac{W_1}{W_o}$  off a graph at the proper  $\frac{W_o}{S}$ , obtain  $\frac{W_E}{W_o}$  from experience (.6 was used in this study), and  $W_o$  is immediately available for any payload.

In this study it was assumed that the machine would be kept at a constant velocity.



An examination of the results shows several important trends:

Figure 2 shows that the range with reasonable efficiencies is about half of that with all efficiencies equal to one. Actually, on these figures, the duct efficiency of  $N_D = .98$  is probably not realistic for all values of  $\frac{W}{S}$ , since this makes the duct losses essentially independent of  $\frac{W}{S}$ , which is not strictly correct. However, the trends are correctly displayed.

Figure 3 shows that it is very difficult to make an SEV with low speed and low base area loading have large range. It was originally desired to have a range of 2500 nautical miles or 2880 statute miles, but at the speeds and loadings chosen this proved to be impossible. Therefore, to go far one must have large loadings and go fast, which may be difficult over the terrain. Better information regarding attainable speeds and allowable base area loadings must be available for the design of machines for Arctic service.

### 3. OPERATIONAL TESTING OF SEV's IN THE ARCTIC

#### 3.1 Results from Operational Tests of SEV's in the Arctic Environment\*

Operational tests of SEV's in cold environments have been performed in the past - to date reports on nine such tests exist. The most completely documented tests were performed by the Canadians on a SR.N5 and on SR.N6 hovercraft at Tuktoyaktuk and Churchill respectively. In these tests cognizance was taken of the results of previous cold weather experience. Chronologically, one may outline the major tests in an Arctic environment as follows:

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\* A comprehensive summary of the SEV Arctic experience is available in a report to ARPA from The Arctic Institute of North America, Ref. 2.

- 1) August, 1964, a 3 ton SK-3 operated by CRREL on the Greenland ice cap around Camp Century, total time about 30 hours.
- 2) February, 1966 a SR.N6 operated by the Swedish Navy on the Baltic, total time unknown.
- 3) April, 1966, a SR.N5 operated by the Canadian and British government jointly, on and about the McKenzie river delta near Tuktoyaktuk, total time about 100 hours. (3)
- 4) October, 1966, commercial operation in Cook Inlet. details unknown.
- 5) February, 1967, a Bell SK-5 operated by Bell Aerosystem on Lake Erie, time unknown.
- 6) January, 1968, a SR.N6 operated by the Canadian Dept. of Transport near and about Churchill, about 130 hours. (4)
- 7) February, 1968, a Bell SK-5 operated by the Canadian government and Bell Aerosystem on Lake Erie, time unknown.
- 8) March, 1968, a SR.N6 operated by the Finnish government on the Baltic, time unknown.
- 9) Two SR.N6's operated commercially on the Alaskan North Slope, details unknown, 1969 to present.

Of these tests, none were specifically designed to evaluate applicability of SEV's to remote ice pack operations such as would be required for Arctic research projects. Although terrain selection encompasses the anticipated environment of most Arctic scientific missions, the most prominent drawback of these tests was the (extensive) use of helicopters for terrain and path reconnaissance. Thus, actual capability in speed and range is difficult to

assess from the test results. This aspect will be discussed in a latter part of this report.

Since experience has shown that to obtain maximum range an SEV must go as fast as possible\*, the actual speeds attained in the Canadian tests bear examination. The advertised maximum speeds of the SR.N5 and SR.N6 are 76 and 69 knots respectively. The best average speed recorded by the SR.N5, with the exception of two runs under special circumstances, was 39.8 knots over a distance of 73 nm. In every case the average speed was on the order of 31 to 40 knots, or roughly half the maximum. Since the range is specified for operation in calm air over a smooth surface, the range and speed performance evaluation for typical Arctic operations needs to be modified. No specific data on average speeds was given in (4) for the SR.N6 trials; however, it is noted that for the first half of the trial, craft speed was restricted by the manufacturers to 30 mph (or 26 kn) over any solid surface. Further, this restriction was removed by pilot's request and "slightly higher speeds were maintained when the pilots felt the surface being crossed was not too hazardous." In high speed runs over a prepared surface the average was about 50 knots. Indications are given of the range limitations of the SR.N6 by the fact that the craft rarely averaged better than 3 gal/mile giving a range of 88 miles. It is interesting to note that the theoretical estimate of fuel consumption for the SR.N6 at 55 mph (47.6 kn) is about 1 gal/mile; actual tests over land on a known course gave 2.42 gal/mile. No general conclusions can be drawn from the SR.N6

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\*Since a large fraction of engine power goes into the lifting fan, fuel consumption increases only slowly with forward speed.

data concerning the scaling of theoretical range and speed performance - such information is vital if the craft is to operate on its own without intensive helicopter support and on some established schedule.

Since the efficiency of an SEV increases with increasing AUW (all-up weight) one is concerned with the actual  $\eta \left(\frac{W}{D}\right)_{\text{eff}}$  compared to the theoretical values. The advertised value for the SRN-5 at  $V_{\text{max}} = 76 \text{ kn}$  is 3.89; in Fig. 4 are shown results from the tests at Tuktoyaktuk. It is clear that realizable range is about half the theoretical (Fig 5, 6) since average performance  $\eta \left(\frac{W}{D}\right)_{\text{eff}}$  is 2 or less at realizable speeds over non-prepared terrain. Furthermore, to extrapolate test results to form reasonable bounds on general theoretical estimates, more data are required on different configurations and sizes of vehicles.

In analyzing the primary effects of terrain during these trials, the basic rule of thumb for negotiating ridges appears to be verified: the craft can negotiate ridges, protrusions etc. that are less than 70% of the skirt height ignoring the potential dangers of skirt damage due to obstacle roughness. The principal difficulties arose from the limited maneuverability of the SEV in negotiating rough terrain. Picking a path through ice blocks becomes a time-consuming task when the "clear space" decreases to vehicle dimensions. Of more significance is the problem of crossing terrain depressions, such as ditches or hollows with characteristic dimensions less than those of the vehicle. Sudden loss of cushion pressure could result in a serious accident; this possibility caused the pilots to be extremely cautious in approaching

known depressions. Crevasses or narrow leads in the ice pack could be difficult to detect under in-service operations and hence present a real danger. Some experience in this regard has been accumulated during the commercial operations on the Alaskan north slope where sharply cut creeks in the tundra have on numerous occasions endangered the vehicle and occupants. These creeks often could not be detected until past the safe avoidance distance for the craft.

Navigation capabilities of the SEV are difficult to assess from reported tests since these relied rather heavily on helicopter support and known principal landmarks or routes. Neither would be available during remote pack ice operations, so the question of performance degradation under more severe conditions remains open. Both of the Canadian tests reported that aircraft radio was not satisfactory for communications and that radar was effective for both navigation and steering; however, neither test included substantial offshore sorties.

The tests were possibly most valuable in determining the type of winterization that an Arctic Sev should have. Material problems concerning the skirt system are discussed in great detail in Ref. 3 and 4 as well as physical craft protection systems. Also clearly defined is the need for a dual engine craft, particularly for missions without close helicopter support. Extrapolating this conclusion, it seems logical to incorporate back-up systems to all critical components.

As a final note on the test results, handling characteristics are discussed. In many respects, problems principally identified with other

aspects of SEV operation should really be related to handling capabilities. Fundamental to all the operation phases are stopping distances or acceleration rates and turning radii. Even if one is able to develop suitable navigation instruments to pick the route, the current turning ability would severely limit the speed. Since for craft of every size there will be some terrain features that have to be avoided and the maneuverability problem becomes worse with increasing size, simply building bigger SEV's with higher skirts will not resolve this problem.

### 3.2 Suggested Additional Testing of SEV's in the Arctic

In evaluating the available results from Arctic environment SEV tests it becomes clear that several very serious gaps exist in the data. These all fall in the general category of engineering flight test data to be used in evaluating the theory used in the design of the specific craft tested. It is advised that the next series of tests include experienced flight test engineers (with aircraft industry flight test expertise) and that the following tests be incorporated into the testing program. The list is by no means exhaustive but should serve as the basis of a more complete program to be devised jointly by the flight test engineer and a design engineer with experience on the particular craft to be tested.

The specific engineering performance to be tested is:

- . Steady performance - smooth surface: constant velocity.

Measure power inputs, mass flows, velocities, pressure distribution, fuel flow, height above surface (define

a standard measurement), machine velocity over ground and through air, cross-wind drift rates and correction-induced roll.

- . Dynamic performance - rough surface: continuous record of items listed under steady performance testing, and in addition, accelerations, angles and angular rates with terrain characteristics. One should have enough information concerning the terrain to be able to determine the power spectrum of the terrain as well as the power spectrum of the performance.
- . Stability - static stability defined through heave stability,  $C_m$  versus angle of tilt, lateral and directional static stability and control if possible. Determination of transfer function or response characteristics to impulse and step input of sufficient magnitude excursion to encompass nonlinearities of skirt contact. Stability measurements over a random surface.
- . Control - linear acceleration in starts and stops under various control actions, influence on craft orientation, turning performance, lateral acceleration.
- . Navigation - effects of visibility on average speeds, maneuverability, effects of travel over unmapped terrain, off-shore operation in absence of landmarks, geographic features, evaluation of specific navigation systems under adverse conditions.

In summary, the following quantities should be measured:

- . Power input to fans and/or props
- . Propulsive efficiency
- . Mass flows and velocities at fan
- . Pressure distribution under the machine at several points
- . Fuel flow
- . Height above surface at several points on perimeter under varying operating conditions and terrain
- . Acceleration at center of gravity and pilot station
- . Craft orientation angles and angular rates
- . Velocity of machine over ground and through air

The above constitutes an extensive testing program in its own right, however, it is felt that such data is necessary to realistically evaluate the potential of the SEV in the Arctic (much less to carry out a proper design).

### 3.3 Unsolved Problems and Alternative Transportation Vehicles

The principal problem areas thus far identified are concerned with safety and dependability, all-terrain capability in uncharted terrain, maintainability far away from enclosed facilities, susceptibility to damage, poor fuel efficiency and habitability. As more results from Arctic testing are available and are incorporated into a craft specifically designed for Arctic use, some of the problems discussed may be solved. However, it is felt that a dependable machine for support of scientific missions in the Arctic is still several years in the future and that alternate solutions



to all-terrain all-weather travel in the Arctic should be investigated.

Among the alternate solutions that merit further exploration are 1) STOL-VTOL aircraft with all-weather landing systems for fast, long range operations, and 2) an all-terrain surface vehicle. The all-terrain surface vehicles could be some adaptation of the amphibious, articulated crawler concept, or a hybridization of a number of these concepts including the air cushion. From the viewpoint of dependability, such a craft would have to be reliably powered and equipped with self-rescuing gear (winches, anchors etc). In discussion with scientists engaged in Arctic research it became apparent that such a vehicle would fulfill an urgent need. The necessary technology exists for such a vehicle which might incorporate concepts from swamp buggies, lunar rovers and jet-engine trucks.

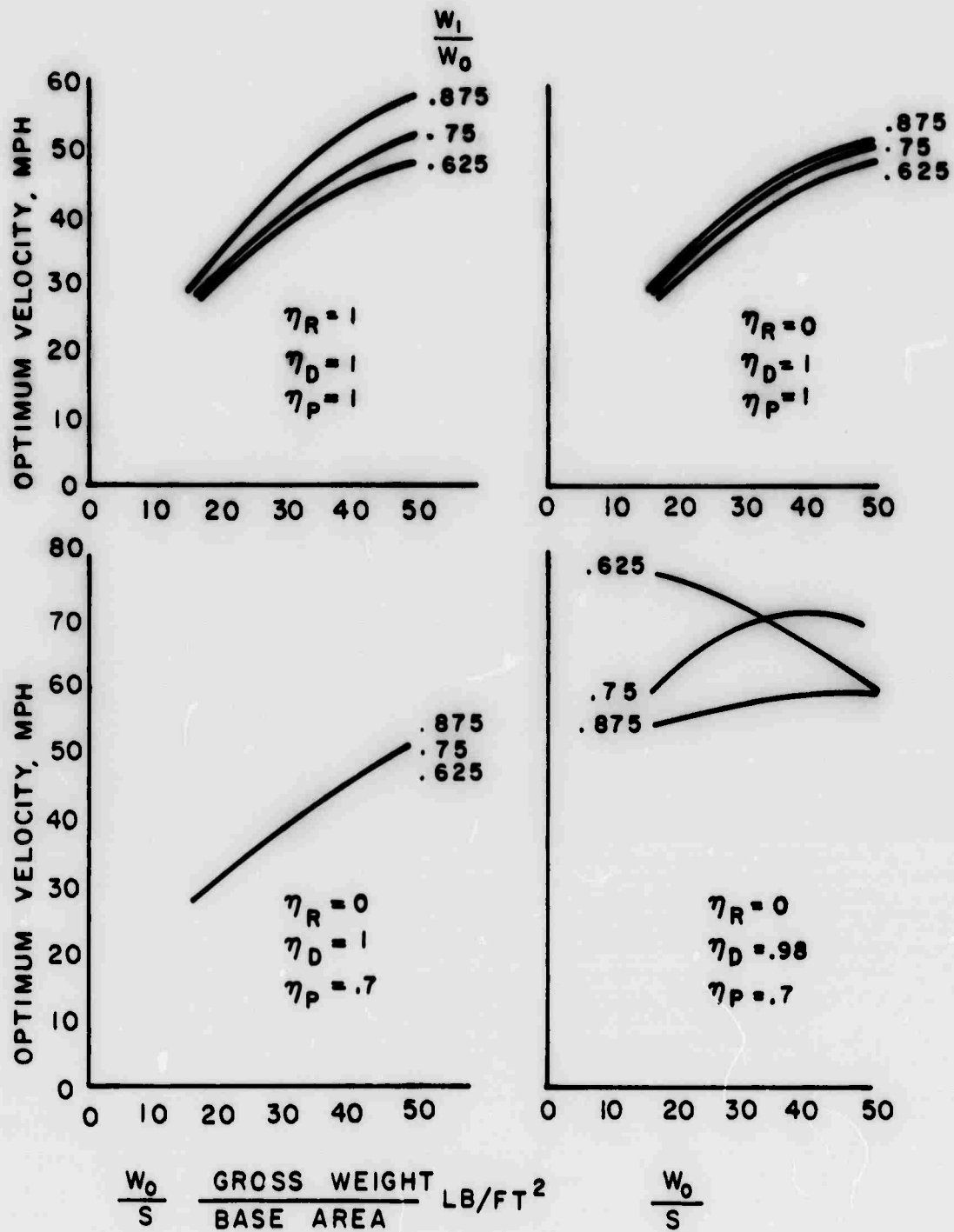


Figure 1. Variation of Optimum Velocity with Base Loading  
Height/Beam = 0.01

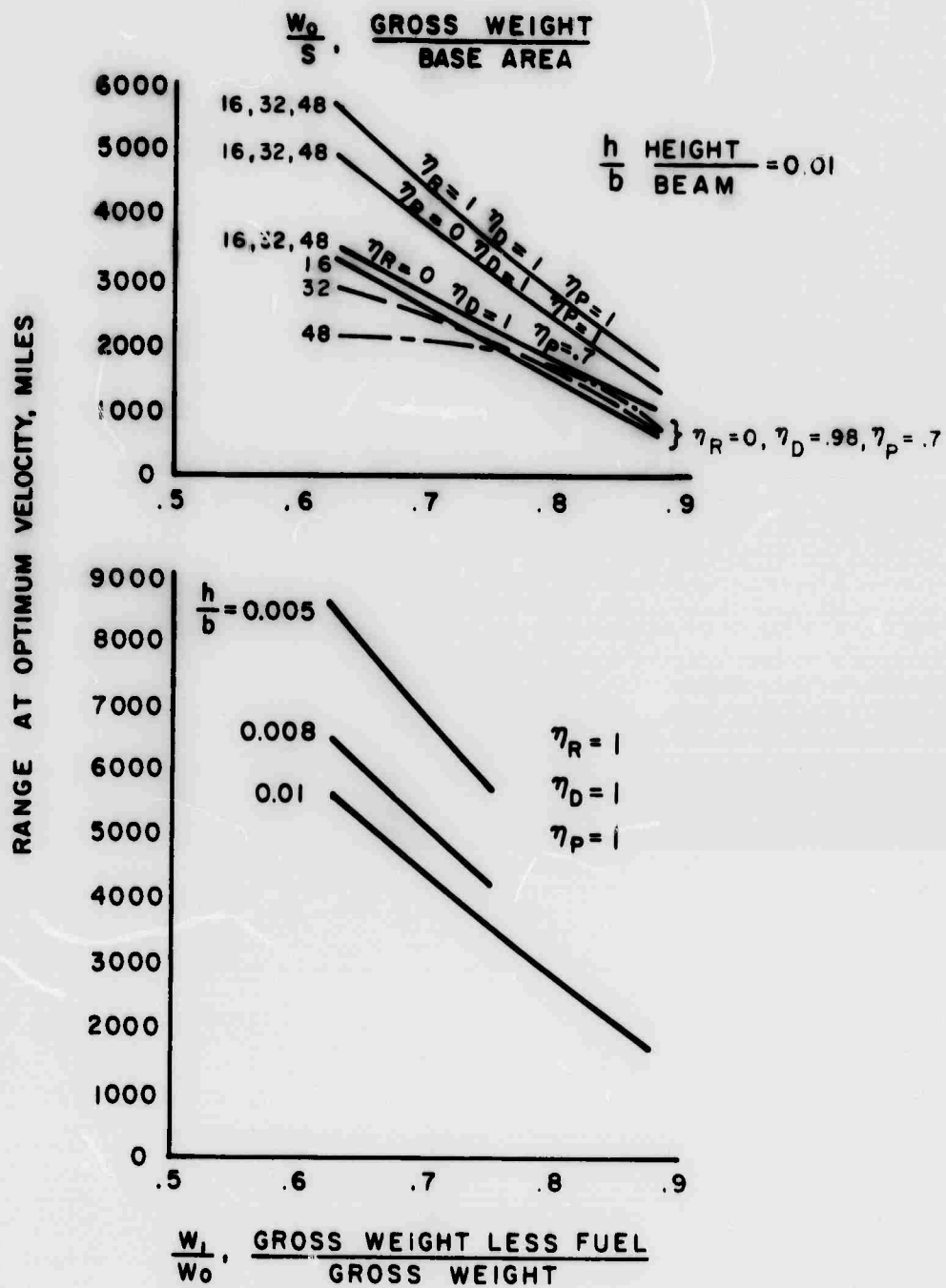


Figure 2. Range at Optimum Velocity

$$\frac{\text{EMPTY WEIGHT}}{\text{GROSS WEIGHT}} = 0.6$$

$$\frac{\text{HEIGHT}}{\text{BEAM}} = 0.01$$

$$\eta_{\text{RAM}} = 0$$

$$\eta_{\text{DUCT}} = 0.98$$

$$\eta_{\text{PROP}} = 0.70$$

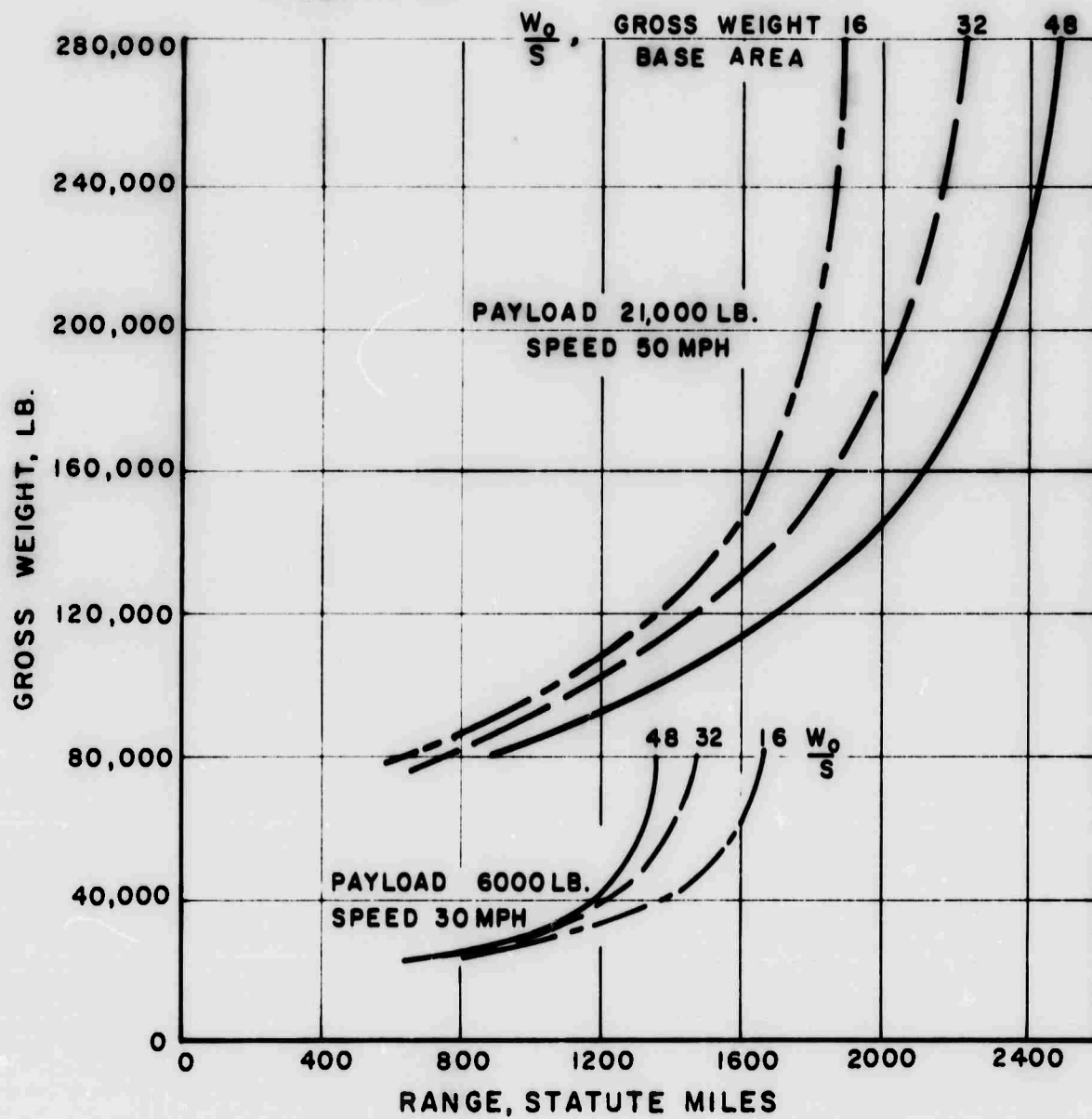


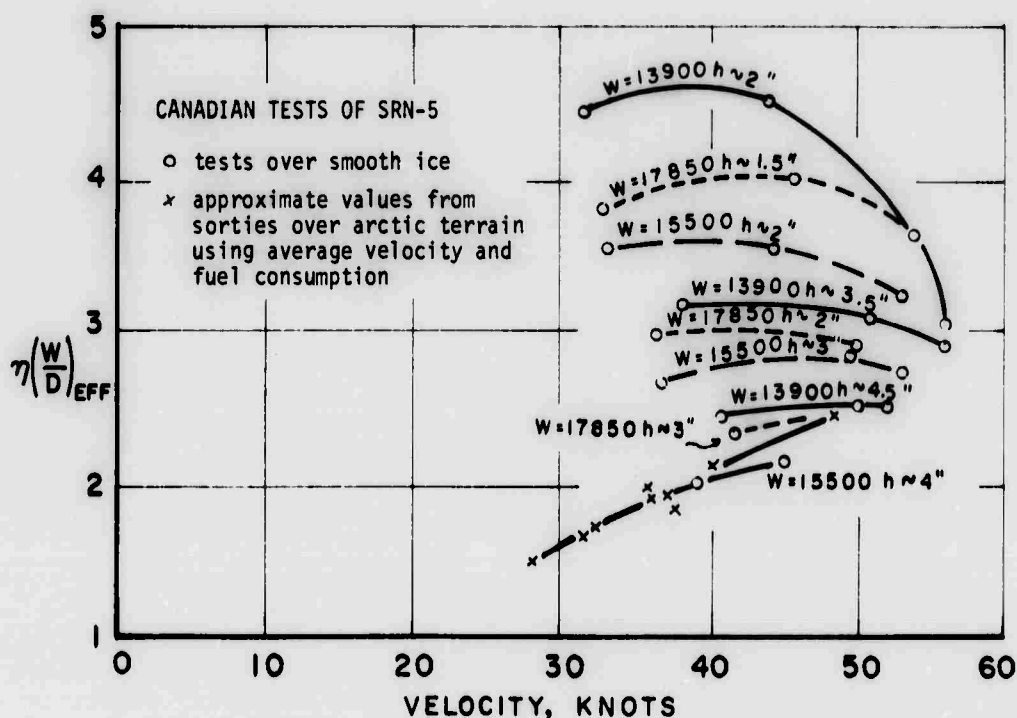
Figure 3. Variation of Gross Weight with Range

Figure 4. Surface Effect Vehicles' Range\*

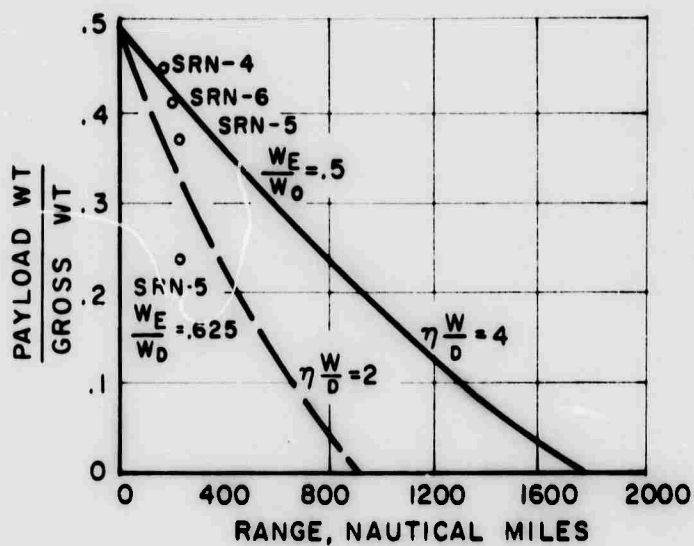
$$R_{N.MI} = 325 \left( \frac{\eta}{C} \right) \left( \frac{W}{D} \right)_{EFF} \ln \frac{W_0}{W_1} \quad \begin{array}{l} W_0 = \text{GROSS WT} \\ W_1 = \text{GROSS WT LESS FUEL WEIGHT} \end{array}$$

$\left( \eta \frac{W}{D} \right)_{EFF}$  FROM ADVERTISED PERFORMANCE

Craft	$V_{MAX}$ , kn	$W_0$ , lb	$S$ , hp	$\eta \frac{W}{D}$ at $V_{MAX}$
SRN-4	77	370,000	18,000	4.85
SRN-5	76	15,000	900	3.89
SRN-6	69	22,400	900	5.27
MITSUI	55	24,000	1,050	3.88
SEDAM	75	68,000	3,000	5.22
CUSHIONCRAFT	60	23,000	1,150	3.48



\*The range equation used here is the Breguet equation and reflects the overall efficiency of a given machine. The equation of p. 13 is a special form displaying component efficiencies and their effect on range.



#### ASSUMPTIONS:

EMPTY WT = .5 GROSS WT

FUEL CONSUMPTION = .5 LB/HP/HR

Figure 5.

PAYLOAD WT = 3500 LB

SUBMARINE	1000 LB
BUOYS	500
MISC. EQUIP.	500
4 MEN & GEAR	1000
FOOD, LIVING	500
	<u>3500 LB</u>

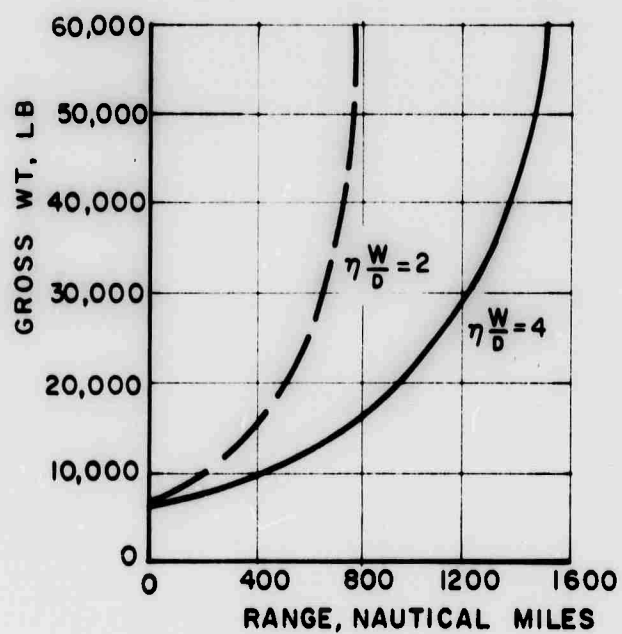
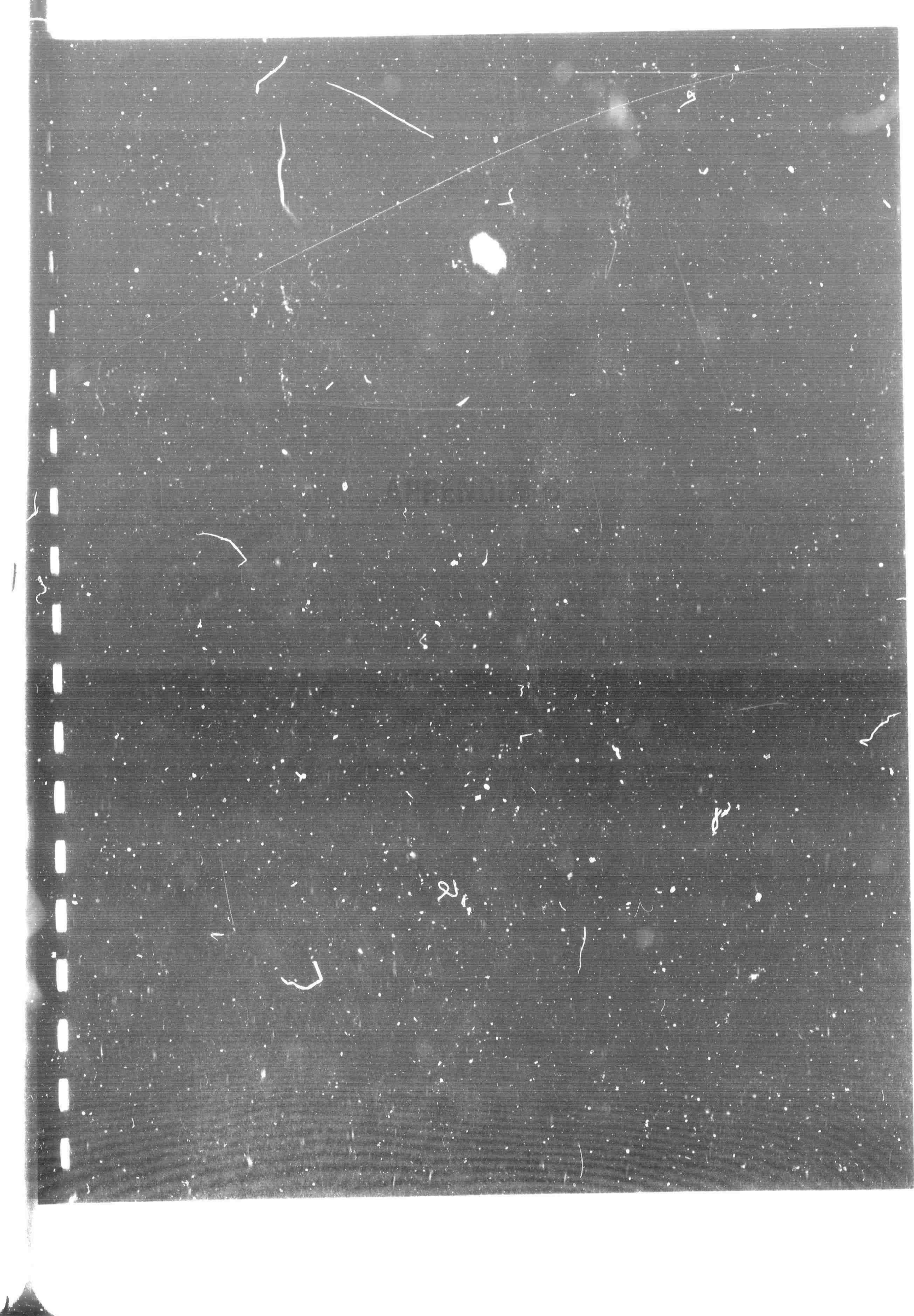


Figure 6.

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**PORTABLE OBSERVATION LABORATORIES FOR ARCTIC RESEARCH  
ICE FLOE SHELTERS / P.O.L.A.R. - ROOM MODULES**

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**Advanced Arctic Technology Program**

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NO. N00014-67-A-0103-0016.**

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## INTRODUCTION

The purpose of the Advanced Arctic Technology Program at the University of Washington is to develop new techniques and new devices to make scientific observations of Arctic oceanic and atmospheric parameters in a more synoptic manner, with greater precision and accuracy, and in a more expeditious manner with decreasing demands on personal discomfort of the scientific investigators and diminishing risk to human life.

One area where technological advances could be of service in furthering scientific observations is shelters and laboratory modules suitable for deployment on floe ice.

The choice of Arctic shelter depends to a high degree on the duration of the stay on the ice field. For a few days a mountain climber tent or snow shelter might be satisfactory, whereas for a longer period of time improved conditions would be required. The insulated tent with plywood floors such as the Jamesway tent would be sufficient through months, but in a camp with a useful lifetime of half or full years shelters with solid walls would usually be preferred.

There is a great deal of literature devoted to techniques of designing a building structure suitable for the Polar environment--structures to be constructed on permafrost or land ice. Good summary descriptions of these techniques can be found in "Beardmore Camp ONE, Antarctica", by James J. Lutz in the "Military Engineer", November--December 1970 and "Mobile and Modular Homes for Cold Regions", by David Schaefer in the "Northern Engineer", spring 1971. However, none of the techniques described therein are exactly suitable for buildings to be deployed on floe ice. In discussion with many scientists and engineers with Arctic experience, a performance specification was derived for structures suitable for floe ice deployment. The task of this sub-project of the Advanced Arctic Technology program at the University was to develop a technique of building that would result in the closest fit to that performance specification.

In addition to the usual requirements for thermal qualities and ease of transportation that any building suitable for high latitude use must have, structures for deployment on floe ice should, if possible, meet these further requirements:

1. Be deployable by aircraft capable of landing on floe ice.
2. If delivered to the site in assembled (not knocked down) shape, the components should serve as cargo containers en route.
3. Easily assembled on-site by persons unskilled in the building trades and while wearing mittens.

4. Easily disassembled and reassembled in components of a size that can be moved about by six or eight men without the assistance of heavy machinery such as tractors.
5. Easily disassembled and reassembled in components capable of being lifted by helicopter.
6. Provide some protection against catastrophic fire.
7. Be inexpensive enough, when produced in quantity, to be abandoned if a salvage attempt would risk human life.

This report describes a construction technique that could produce a modular structure that meets these specifications.

#### GENERAL DESCRIPTION

The proposed room module system, the P.O.L.A.R. - Module system,\* consists of 8 by 8 by 8 ft. room modules which have side walls but no end walls. The room modules can be closed in the ends with separate 8 by 8 foot end panels.

The two parts, room modules and end panels, are made lightweight and can relatively easily be pushed or pulled in place by four-five people.

The room modules can be connected to each other and to the end panels through a simple buckle connection. It only takes a few minutes to connect a room module with another room module or with an end panel.

To keep the room modules lightweight the side walls, the floor, and the roof is made as a continuous sandwich panel consisting of polyurethane foam with aluminum skin inside and outside.

The end panels are made in two versions; a fireproof end panel made of steel, asbestos, and fiberglass, and a lightweight end panel made of wood, polyurethane foam, and aluminum. Through a considerate combination of room modules and fireproof end panels the total shelter will have fire walls separating the various zones of use.

Doors and windows can be placed both in the side walls of the modules and in the end panels. In the fireproof end panels, fire doors can be installed.

---

\*Portable Observation Laboratories for Arctic Research - Modules

## DESIGN PRINCIPLES

In Arctic design it is seen time after time that basic design principles can have opposite requirements. A typical example is that all rooms and buildings should be built close together for minimizing heat loss, but be spread far apart for minimizing fire danger. Following all the design requirements was found to be impossible, so the final design is therefore a compromise which can be challenged by people who feel that the selected compromise should have been more in another direction.

The goal was to design room modules which easily could be connected with each other and which could be transported by medium sized helicopters. A survey of existing prefabricated huts made both for commercial and military purposes did not reveal any system which satisfied the above mentioned design goal.

Experts involved in the design and construction of systems with more or less the same design requirements as the Arctic modules were consulted. They included the fields of housetrailers, ships, airplanes, large (heavy) containers, and smaller (light weight) military transportation cases. None of the existing related designs could directly be transferred to the Arctic module design. For example, the superb fire safety in ship design is obtained at the cost of heavy weight materials, and the lightweight construction in airplanes is made without sufficient considerations for thermal breaks.

Having not found a construction method which directly could be transferred to the module design, the emphasis was then placed on seeking out materials which might be useful in a design developed especially for the planned modules.

## MATERIAL SELECTION

For any structure which will be subjected to rigorous polar conditions, the choice of materials is no less important than the actual design process. It is essential that the designer have a working knowledge of the physical characteristics of a myriad of materials. In this way he can weigh some against others and arrive at a structure which will have desirable thermal and structural properties, in addition to any specific characteristics of weight, cost, etc.

After consultations with representatives from the shipping and aircraft industry in the area, it was decided that an initial module prototype should consist of two monocoque shells with some kind of foam core in between. A sophisticated form of this system is the "stressed skin panel" which is eventually partially employed. Because thin, light, and waterproof shells are desirable, the decision was made to use either molded fiberglass or aluminum sheeting. Both systems are relatively light, but the final decision was to use aluminum skins.

All additional materials, such as edge and corner reinforcements, gussets, etc. should, not to complicate the matter, either consist of simple, traditional materials, easy to work with, or of prefabricated shapes.

The materials chosen are in view of limited money for development and limited time available for actual construction. Most of the materials can be worked and assembled by no more than two people in a simple shop with a minimum of tools. It would be advisable to employ different systems for future prototypes which would easily lend themselves both to mass production and to a local production, for example at the Naval Arctic Research Laboratory at Point Barrow, Alaska.

#### Aluminum Skin

To insure a weathertight shell, it is best to have as few exterior joints as possible. This is accomplished by the use of trailer roof sheet. By using the aluminum in full module width, 8 feet (244 cm), the sheet can be wrapped around the module leaving only one seam. The specific type of aluminum chosen is alloy 3003 H16 in a thickness of .040". This aluminum is relatively inexpensive, the sheet can easily be bent for both sharp and round corners, and it is relatively easy to cut and work with while providing good rigidity and dent resistance.

#### Foam Core

It was decided to use a foam core which not only has excellent thermal characteristics but also has admirable structural characteristics. A rigid, closed-cell polyurethane foam satisfies the given requirements and is used in two densities.

In the corners there is a 4 lb/cu. ft. foam to provide extra strength. In the walls there is used the lighter 2 lb/cu. ft. foam to cut down on weight where excessive strength is not needed.

The closed-cell foam provides a natural vapor barrier so no additional vapor barrier is needed.

To prevent thermal shock when the hot foam (about 250° F/120°C) comes in contact with the cooler aluminum skin (air temperature in foaming shop) with the result of poor bonding between aluminum and foam, a special primer is applied to the insides of both aluminum shells.

#### Extruded Aluminum Corners

To reinforce the round corners in the aluminum sheeting, aluminum was again chosen for low cost and high strength. The choice was an "off-the-shelf" extruded shape (ALCOA die 45875) which has exactly the radius needed and has a y-web reinforcement to distribute load and take the stresses from the corner lashing rings.

### Wood Edges and Steel Gussets

To separate the skins and take the transverse load induced through the buckle attachment system, two end frames are provided on each module. Wood is chosen for its versatility and simple qualities of construction. The use of wood enables the frames to be built by unskilled labor. The type of wood chosen was Douglas Fir (coast region) clear vertical grain. This wood is straight with no knots and is good in appearance. A 1 x 4 (actual size 3/4 x 3 1/2 in/19 x 89 mm) acts as the flange and a 2 x 4 ripped to 2 1/2" (64 mm) acts as a web and provides thickness for the screws from the buckle system. To stiffen the frame, steel angle gussets of 2 1/2 x 1/4 in (64 x 6mm) flatbar are glued and screwed into the wooden web in the corners.

### Buckle Connections

To provide the modules with a strong and versatile attachment system, a series of quick-disconnect buckles is provided. The buckles are light and strong. The size chosen is easily attached to the wood end frames and they take up a minimum of space. The buckles are placed on 16" centers along the module to module, and module to end panel joints inside, and a false floor system provides a smooth floor by hiding the floor buckles.

### Lashing Rings

In order to pull the module around and lash it during transportation and on the site, lashing rings are found at the top and bottom corners of the module. Variable length lashing rings are placed through holes in the corner reinforcement and outer skin. The hard plastic shell of the ring component is light and strong, and the stainless steel ring itself resists the forces of weathering. The ring system is designed to fail at the joint between the ring and the plastic shell, so that no damage to the module wall will result. The lashing rings are designed for use in refrigerated shipping containers and therefore minimize heat transfer through the wall.

### Weather joints

The joint system between the modules and between the modules and the end panels is of a type which is not dependent on complicated detailing and weather stripping. Modules may be in outdoor storage in the snow and cleaning of the edges should be made without destroying the joint detailing.

On the prototype module various weather joint systems can be fastened as inserts. The wood edge shape is for that reason made very simple. After testing of different weather joints and a final joint type is selected, the module edge can be redesigned for this joint type only.



## CONSTRUCTION PROCESS

### Forms

When construction on any kind of prototype begins, it should be clear whether the project will produce large quantities. If mass production will take place, then expensive forming costs can be spread out to a small amount per unit produced.

For this project, which is an examination of various technological applications of new material combinations, eventual mass production could not be assured. Thus, an inexpensive forming system which is versatile enough to adapt to any design changes during the construction of the first module would be the answer.

To avoid the great amount of labor required to build forms from scratch, and also avoid having unusable form materials to take care of at the termination of the program, an "off-the-shelf" form system was required.

In many ways, the module construction of aluminum skins with a continuous foam core resembles concrete wall construction. Thus came the idea of forming the module as if it were a concrete wall. A rental transaction therefore took place for the acquisition of forms used in the pouring of concrete walls.

The forming system consists of panels 8 feet long and in widths of 12 inches and 24 inches. The form panels are treated 3/8" in plywood sheets backed by steel angle reinforcing. The forms are placed with the 8 foot dimension running vertically and tied to each other through holes by using small steel wedges. At the outside corners, steel angles connect panels perpendicular to each other. At the inside corners, a special corner piece is used. At 12 in, 36 in, and 72 in, double 2 x 8 members are connected to the outside face of the forms by special waler fittings. The waler 2 x 8 members serve to brace the panels in the horizontal direction and assure a straight wall. At the top and bottom of the forms, the inside form wall and outside form wall are spaced and connected by ties and wedges. Thus, the 2 x 8 bracing holds the forms tight and straight both inside and outside.

The form work is built up so the open ended module is standing on one end with the floor and ceiling placed vertical together with the two side walls.

### Module construction

The actual building of the module wall is made in the following steps:

1. The interior form is assembled on a flat, hard surface, for example on a concrete floor.

2. The inside aluminum skin is wrapped around the interior form. The square corners are in advance bent on a standard press brake. The seam is made along a corner and riveted tight in a simple lap (at 4 in/ 10 cm center-center). The seam will be hidden under the future raised floor.
3. The aluminum corner extrusions with parts of the wooden end frames preassembled is pressed toward the inside aluminum skin from all four corners. In the y-web of the aluminum extrusion holes are burnt out\* for added foam bond. Close to each end of the extrusion are drilled holes for the hidden parts of the lashing ring system. Wood blocking is glued to the y-web at the lashing ring holes. Attached to each end of the aluminum extrusion are pieces of the end frames extending to the middle of the module wall, floor or ceiling. The exterior wood board flange is continued in the round corner inside the aluminum extrusion in a separate piece of wood cut to shape.\*\* In the other end the exterior wood board flange does not extend to the middle of the module wall. It is replaced with a gusset piece made of the same dimension material connecting the end panel parts coming from each module corner.\*\*\* Both preassembled and assembled on site wood parts are glued together with plastic resin glue. The connection of the end frame parts to the aluminum extrusion is made with rivets and with neoprene base glue. The same glue is used on the inside of the interior wood board flange for connection with the inside aluminum skin.
4. All surface of inside aluminum skin and corner extrusions which will be exposed for bonding with polyurethane foam is covered with thermal shock primer. It will prevent thermal shock in the foaming process, a condition which can result in lack of bonding between the foam and aluminum. Careful application on the inside of the extrusion with its y-web is needed.
5. Module wall thick foam studs 4 by 4 inches (about 10 x 10 cm) cut of polyurethane sheets are glued to the inside aluminum skin from end frame to end frame. They divide the wall up in sections for the following purposes: a. Separating the high density foam along the corners from the low density foam on the large wall surfaces between the corners, and b. Dividing the wall up in foaming zones.

---

\*Drilling was found to be too complicated because of the curved extrusion shape.

\*\*Soft plastic sheet in the same thickness and height as the flange was easy to bend in place but was for other reasons not found usable. For example the connection method decided on for connection of the wood edge system to the aluminum extrusion could not be used.

\*\*\*Various types of cuts in the web ends, where they meet, were tried.

6. Thermal shock primer is applied on the surface of the outside aluminum skin which will be exposed for the polyurethane foaming.
7. The outside aluminum skin is wrapped up against the module wall framing, starting from a future bottom corner. To secure a close connection to the wall the exterior form panels are placed gradually as the wrapping takes place. Neoprene base glue is applied on all the framing parts (aluminum extrusions, wooden end frames, and foam studs) on a wall side immediately before the aluminum skin is pressed up against it. Between the exterior round corner of the module and the square corner of the exterior form a form piece shaped to follow the round corner shall be inserted.\* The outside skin seam is made to be under the floor with overlapping over a straight side of the corner extrusion. Rivets at 4 inches (10 cm) center-center fasten the overlap to the extruded aluminum.
8. The complete form work with the module wall framing inside shall be adjusted for exact square shape of the module cross section. Outside and inside form bracing can be placed.
9. Holes for inserting the foaming hose through the web in the wooden end frame can be made in advance as voids in the web.\*\* Then the actual foaming can take place. The form work can be taken down 48 hours after the foaming is done.
10. Finishing up the basic module consists of:
  - Fastening corner angles over the exposed edges of the outside and inside aluminum skin.
  - Fastening two 2 x 4 foundation runners under the bottom of the module.
  - Fastening buckles for the module-to-module and module-to-end-panel closing system along all interior edges at 16 inches (about 40 cm) center-center.
  - Drill and cut holes through the outside aluminum skin for fastening the lashing rings to the hidden part of the lashing ring system.

---

\*In the prototype in some corners triangular cut strips were used. In other corners nothing was used.

\*\*In the prototype holes were drilled, 2 for each foaming section. Hole diameter same as the web height.

Paint the exposed parts of the wood edges for general protection.

Fasten the weather joint system to the wood edges.

(The wood edge corner gussets of steel can be placed hidden on the "inside" of the wooden web if they are placed before the assembly of wooden edges and aluminum extrusions. On the prototype they were placed after the foaming had been done. For giving a similar shape all the way around the wooden edge for the weather joint system, plywood in the same thickness as the gussets (1/4 in/6 mm) was laid in on the web between the gussets.)

Painting the module outside in a highly visible red color.

11. Additional work to do on the module can consist of:

Cutting holes for windows and doors. Install the windows and doors.

Making the raised floor, with or without built-in utility systems.

Applying final wall , ceiling , and flooring materials inside the module.

#### ADDITIONAL BUILDING COMPONENTS

The basic module consists of a continuous floor, side wall, and roof construction only. It can be combined with other modules and with end panels and fire end panels and they can make useful room systems. It can satisfy most of the shelter needs on a drifting station including sleeping quarters, laboratories, and mess hall.

In actual use the modules can through different additional building components be made to fit special requirements. Each of those building components require special studies before they can be described for high Arctic use, and for that reason they are not included in the present study.

Some of the more important additional building components are:

1. Raised floor.

A floor system lifted 2-3 inches (5 - 7.5 cm) above the module floor. The lifted floor gives advantages, such as space for a heated sub-floor and space for pipes and conduits.

2. End panels.

Lightweight end panels for use as interior partitions or as exterior walls. With or without windows and doors.

3. Fire end panels.

Fire walls built up of materials which satisfy requirements similar to those used for passenger vessels.

4. Exterior windows and doors.

Windows of a size and type which are useful for emergency escapes but which do not have less insulation value than triple glazing.

Exterior doors of a type which can easily open both out (for emergency escape) and in (for emergency entrance) without regard to the different snowdrift and ice pedestal conditions.

5. Utility systems I, Water and sewer.

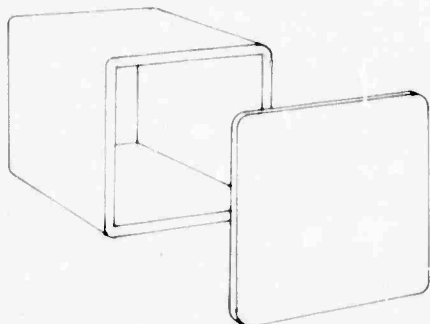
6. Utility systems II, Heat and ventilation.

For ice floe shelters located on ice floes of typical thickness (3-4 meter/ 10-13 feet) it may be possible to develop a heat pump system taking advantage of the little distance between the very different temperatures which, especially in the winter can be found in the air above the ice floe and in the water below the ice floe.

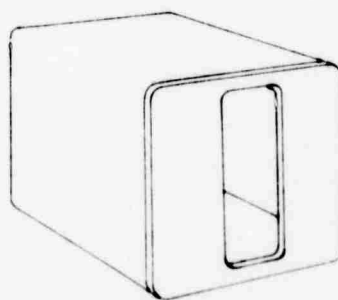
7. Utility systems III, Electricity.

8. Substructures and foundations.

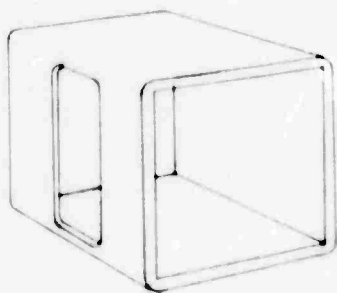
One of the problems connected with building on floating land ice and sea ice is the pedestalling. Research into substructures and foundations includes studies on pedestal skirting, sled runner systems, and suspension systems for whole buildings.



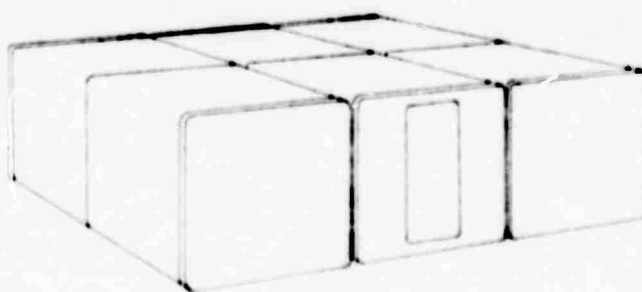
MODULE AND END PANEL



MODULE WITH DOOR OPENING IN END PANEL

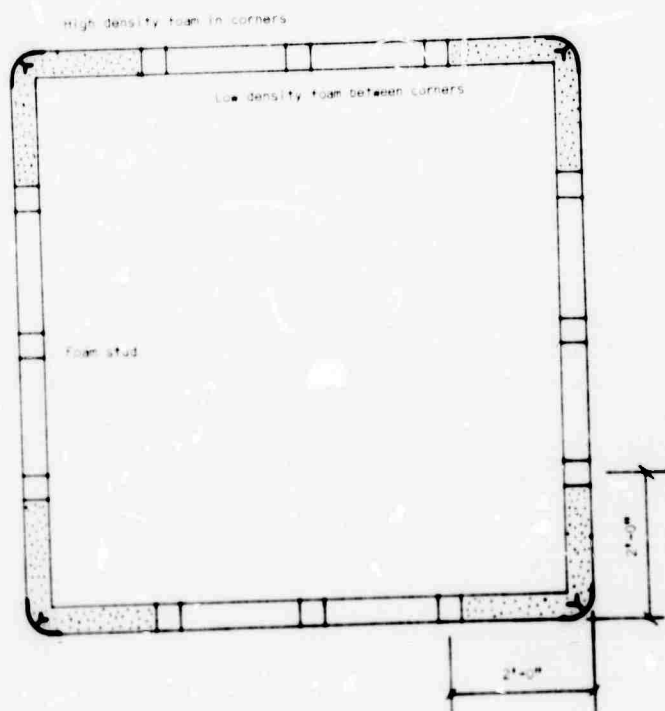


MODULE WITH DOOR OPENING IN MODULE WALL



MODULE SHELTER





CROSS SECTION

FOAMING ZONES  
(3/4" = 2')

SECTION DETAIL WITH ALUMINUM CORNER  
EXTRUSION AND LASHING RING

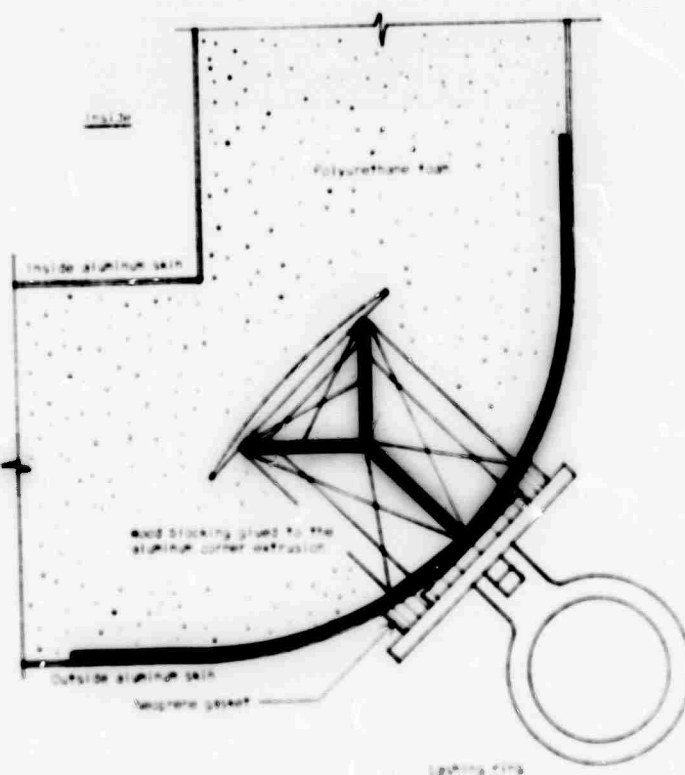
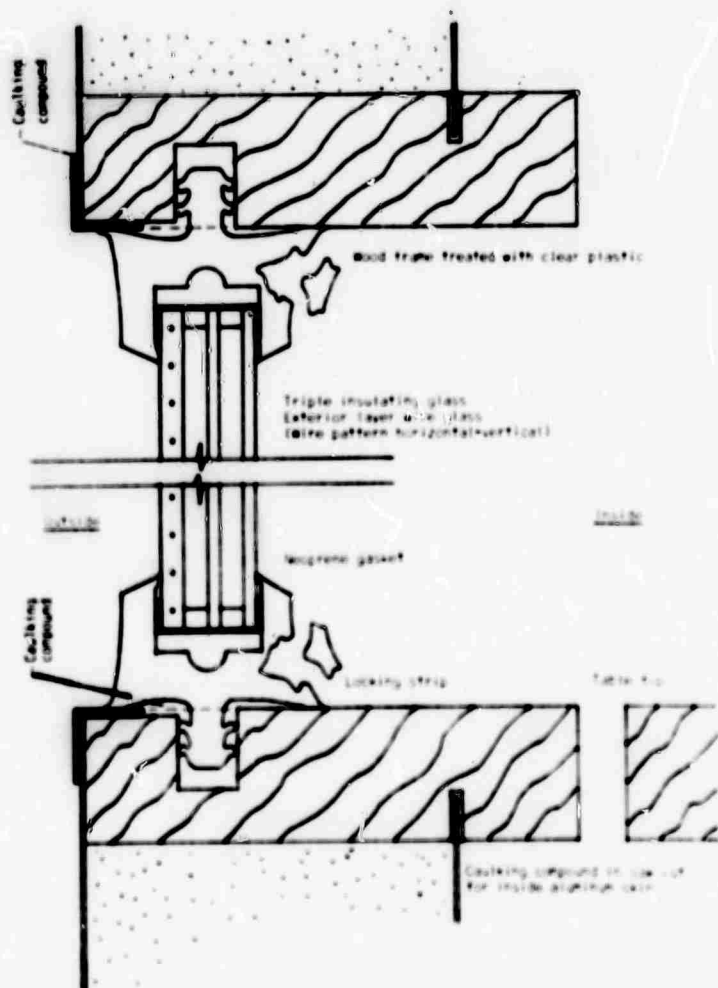
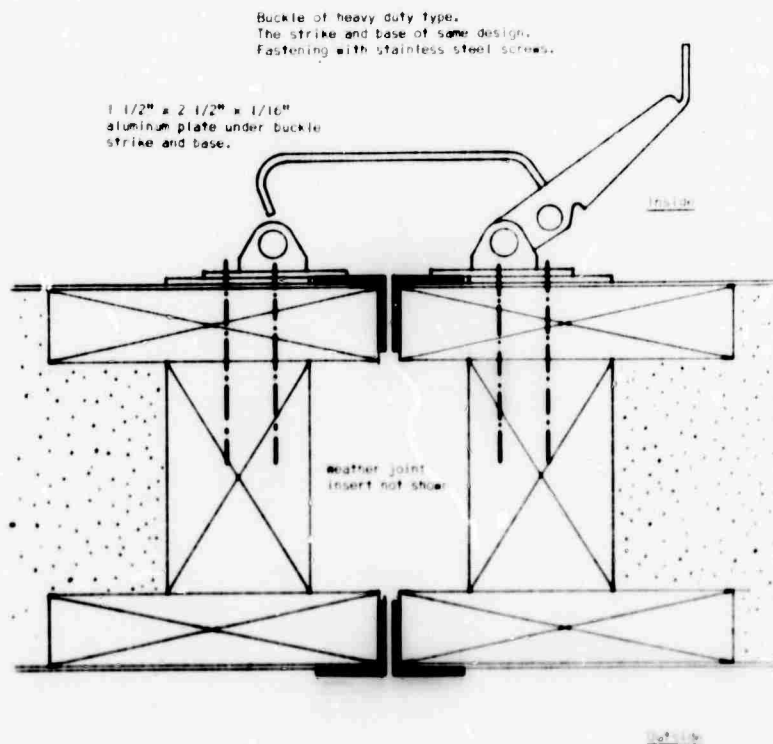


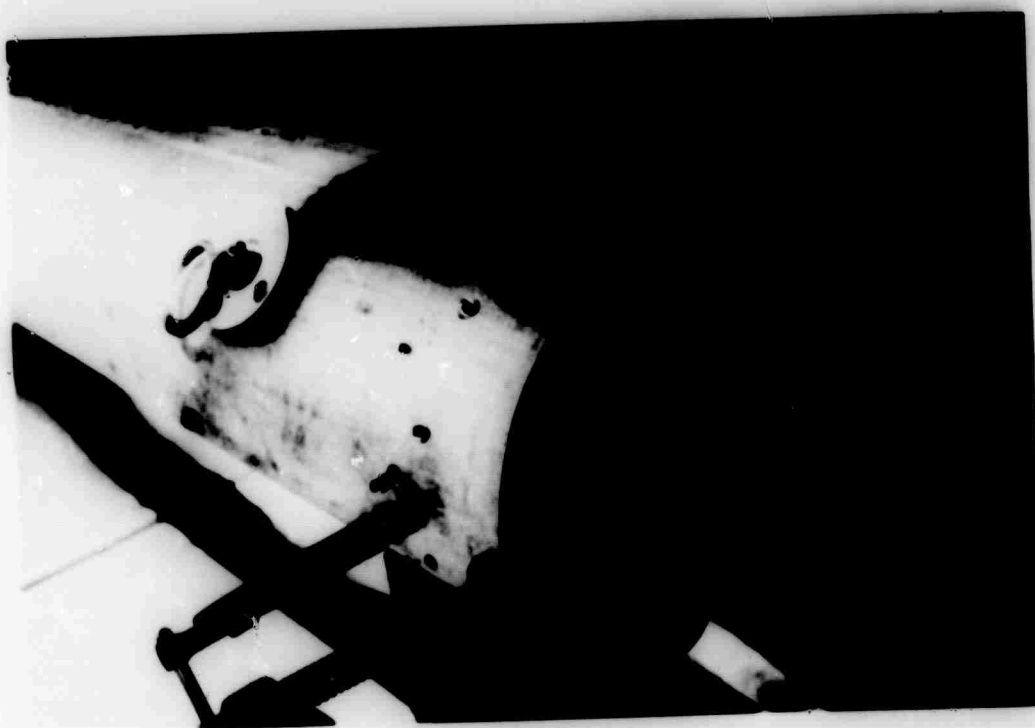
Fig. 20



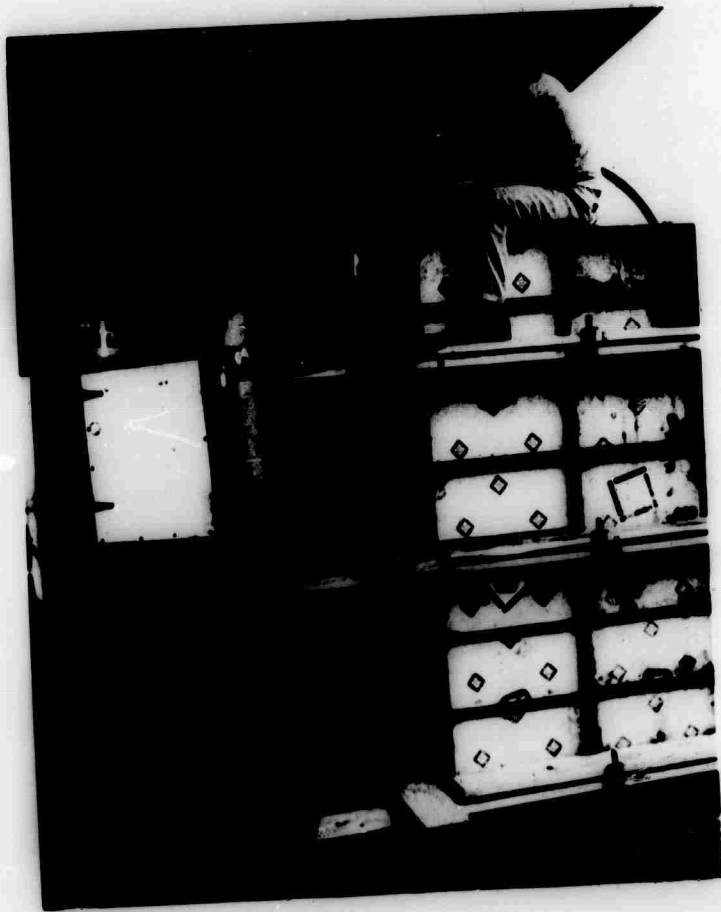
**SECTION DETAIL WITH BUCKLES  
HALF SIZE**



**SECTION DETAIL OF SUGGESTED WINDOW  
WITH TRIPLE GLAZING IN NEOPRENE  
ZIPPER GASKET, HALF SIZE**



ALUMINUM EXTRUSION CONNECTION TO WOODEN FRAME



THE FOAMING PROCESS.  
EQUIPMENT PLACED ON  
SMALL FORK LIFT.

FABRICATED  
MODULE



## APPENDIX I, STRUCTURAL THEORY

The design of the P.O.L.A.R. module is based on an on-site foaming process resulting in a continuous foam core separating the two aluminum skins. Due to the continuity and thickness of the core, the module acts as a rigid frame with the foam and aluminum resisting loads. Two design processes are employed in the structural calculations, one for the design of the flat sections, and a separate one for the design of the corners.

- A. The design of the flat sections (walls, floor, and ceiling) is based on stressed skin theory where the flexural behavior of the foam-aluminum sandwich panel is similar to that of a wide flange section.

In the case of the module construction used, the aluminum skins act as flanges to take tensile and compressive stresses induced by the dead and live loads. The core of foam acts to increase the moment of inertia of the section by separating the skins, and also participates in accommodating the forces of shear.\* Therefore, the design of the flat sections involves the determination of skin thickness based on flexure. Then a check is made for shear in the core, and foam-aluminum bond.

Design of aluminum skin based on buckling:

$$t_a = \frac{W(L^2)}{32,000t_c}$$

$t_a$  = aluminum facing thickness (in)

$W$  = uniform distributed load (psf)

$L$  = span (ft)

$t_c$  = core thickness (in)

Design of foam core based on shear:

$$t_c = \frac{WL}{168}$$

$t_c$  = core thickness (in)

$W$  = uniform distributed load (psf)

$L$  = span (ft)

Design of foam core based on bond:

The use of the thermal shock primer insures foam-aluminum bond. Tests at the site showed that the bond is such that shear in the core will always govern.

---

\*In actuality the foam participates some in resisting bending, thus affording an additional factor of safety.

- B. The design of the corners is accomplished by straight flexural behavior calculations of the cross section. Due to the fact that the aluminum skin is continuous on the outside and inside, stressed skin behavior can not be assumed. Any compressive or tensile stress induced by load will not be taken up through the skins, for the skins will just open up (pull away from the core). For this reason, bending moments in the corners are assumed to be resisted by the flexural capacity of the foam core only!

Design of the foam core based on bending:

$$M = \frac{W(L^2)}{14}$$

W = distributed load (plf)

L = span (ft)

$$S = M/f$$

S = section modulus (in<sup>3</sup>)

M = bending moment (lb in)

f = bending stress (psi)

$$S = \frac{b(h^2)}{6}$$

S = section modulus (in<sup>3</sup>)

b = base width (in)

h = section height (in)

The design of the end frames is based on the assumption that the frames themselves do not participate in carrying loads, but only serve to protect the foam in the ends, accept the screws from the buckle fastening system, and anchor the corner extrusions during the foaming process.

The design of the corner extrusion reinforcement was somewhat simplified and the results of future tests on the module will prove or disprove their adequacy. They were picked as an "off-the-shelf" item to fulfill the need of providing dent resistance behind the corners. The y-web reinforcement will serve to distribute the impact loads that might be received on the corners, while at the same time providing an anchor for the container lashing rings used at the corners.

The design of the container rings was again a case of the acquisition of an "off-the-shelf" item to fulfill specific needs. The versatility of the ring (variable extension) will make it useful for many applications. The ring itself provides a 1000 lb tension capacity when properly installed. It would thus appear that one ring would be adequate to carry the 800 lb module under the most extreme loading conditions that could be imagined. The additional rings provided at the corners are for stable lashing during transportation.

## APPENDIX II STRUCTURAL CALCULATIONS

### Roof Loads

material dead load .....	15 psf
snow live load .....	45 psf
wind suction live load .....	-36 psf
*worst condition is combination material dead load and snow live load .....	60 psf

### Windward Wall Loads

material dead load .....	15 psf
wind live load .....	42 psf
*worst condition is wind live load only .....	42 psf

### Leeward Wall Loads

material dead load .....	15 psf
wind suction live load .....	24 psf
*worst condition is wind suction live load only .....	24 psf

### Floor Loads

material dead load .....	15 psf
floor live load .....	60 psf
*worst condition is material dead load and floor live load .....	75 psf

Design of aluminum skin for flat sections based on buckling:

$$t_a = \frac{W(L^2)}{32,000t_c}$$

assume core thickness is 4 inches.

$$t_a = \frac{(75 \text{ plf}) (6 \text{ feet}^2)}{32,000 (4 \text{ inches})}$$

$$t_a = .021 \text{ inches}$$

Design of foam core for flat sections based on shear:

$$t_c = \frac{WL}{168}$$

$$t_c = \frac{(75 \text{ plf}) (6 \text{ feet})}{168}$$

$$t_c = 3 \text{ inches}$$

Design of foam core corners based on bending:

Worst moment condition at top of windward wall due to wind live load (lateral) only. A moment of 501 lb ft (6012 lb in) tends to open this corner up.

$$M = 6012 \text{ lb in}$$

$$S = M/f$$

$$S = 6012 \text{ lb in}/125 \text{ psi}$$

$$S = 48 \text{ in}^3$$

$$S = \frac{b(h^2)}{6}$$

$$4 \text{ in}^3 = \frac{(12 \text{ in})(h^2)}{6}$$

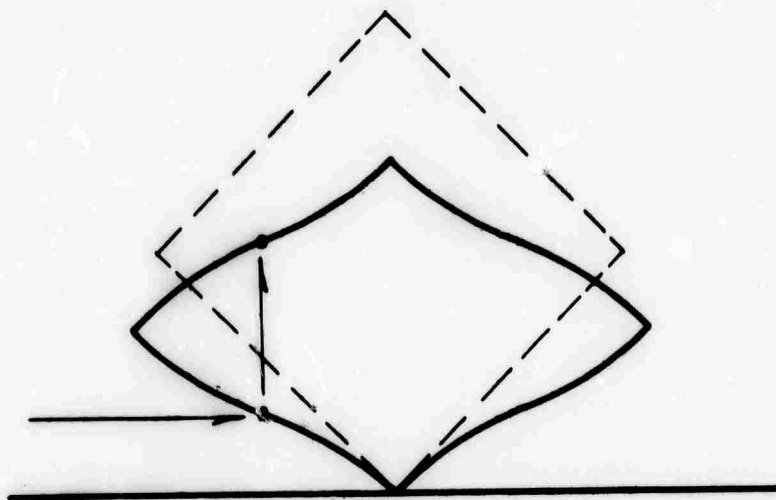
$$h^2 = 24 \text{ in}^2$$

$$h = 5 \text{ inches}$$

#### GROUND IMPACT ON MODULE

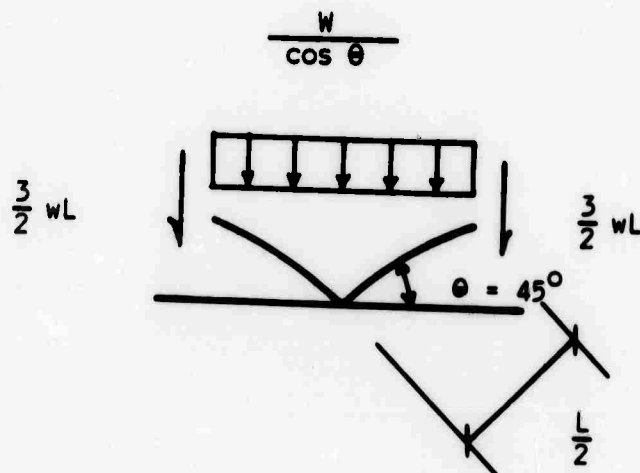
The worst moment in the panels occurs at the contact point with the ground, where the total module mass contributes to the bending produced by de-acceleration.

Inflection pts.





assuming uniform panel weight in lbs/ft = w;



$$M_{\max} = \frac{3}{2} WL \left( \frac{L}{2} \cos 45^\circ \right) + \frac{W}{\cos 45^\circ} \frac{\left( \frac{L}{2} \cos 45^\circ \right)^2}{2}$$

$$M_{\max} = \frac{3}{4} WL^2 \cos 45^\circ + \frac{WL^2 \cos 45^\circ}{8}$$

$$\underline{M_{\max} = \frac{7}{8} WL^2 (.707) = .62 WL^2}$$

$$t_a = \frac{WL^2}{32,000t_c}$$

$$32,000 \cdot t_c \cdot t_a = W \cdot L^2$$

$$\frac{WL^2}{8} = \text{Moment per ft} = \frac{12 \text{ in } (32,000 \text{ psi}) 4"(.04")}{8}$$

$$\text{where } t_c = 4 \text{ in}$$

$$t_a = .040 \text{ in}$$

$$\underline{\underline{\frac{WL^2}{8} = 7860 \text{ lb in} = M \text{ safe/ft width.}}}$$

Equating  $M_{\text{safe}} = M_{\text{max. (ground impact)}}$

$$.62WL^2 = 7860K''$$

$$W_{\text{safe}} = \frac{7860K''}{.62 (8')^2 96''}$$

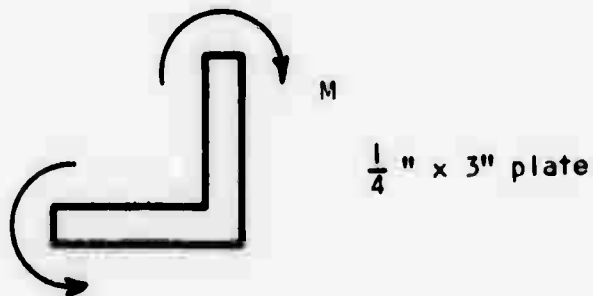
$$W_{\text{safe}} = 16.1 \text{ lbs/ft.}$$

this load can be carried elastically upon impact.

$$W_{\text{actual}} = 2 \text{ psf.}$$

hence the panel can withstand approximately =  $\frac{16.1 \text{ psf.}}{2 \text{ psf.}} (g)$   
= 8 g deacceleration

Corner plates



$$S = \frac{bh^2}{8} = \frac{1/4'' (3'')^2}{8} = .281 \text{ in}^3$$

$$M = S \cdot \sigma = 20 \text{ ksi } (.281 \text{ in}^3)$$

$$M = 5.6K'' = 5600 \text{ lb in per plate.}$$

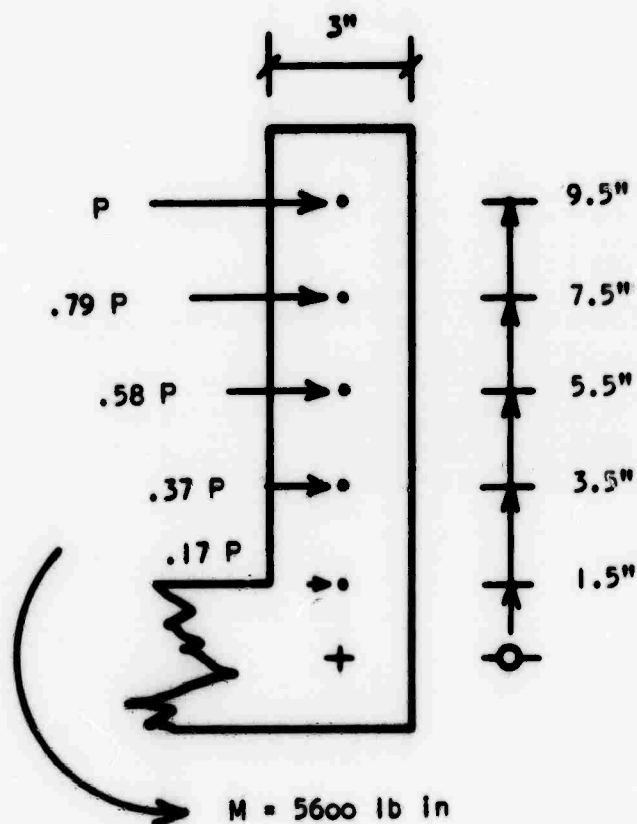
For two plates.

$M = 11,200K"$  which helps stiffen the edges locally, since this is the equivalent of = 17 inches width of module.

(it may be difficult for screws to develop this moment.)

corner plate -  
connector force (screws)

assuming plate dimensions below:



$$P(9.5") + .79P(7.5") + .58P(5.5") + .37P(3.5") + .17P(1.5") = 5600 \text{ lb in}$$

$$20.16"P = 5600 \text{ lb in}$$

$$P = 278 \text{ lbs maximum screw force.}$$

Use 14 gauge wood screws 2" long

## CONCLUSIONS

### Aluminum

Based on the buckling formula, an aluminum thickness of .021 inches is all that is required. However, based on possible floor point loads (desk legs etc.) and puncture forces in the exterior skin, a thickness of .040" will be chosen having a good puncture resistance of 150 psi when backed by foam.

### Foam

Based on thermal insulation requirements, only 2 inches of 2 lb/cu ft density polyurethane foam is needed in the flat sections.

Based on foam core shear, a 3" thick foam cross section is needed in the 2 lb/cu ft density for the flat sections.

Behavioral analysis of the module under impact forces is based on an assumption of 4 inches for the flat sections.

Based on bending in the core at the corners, a cross sectional thickness of 5 inches is needed when 4 lb/cu ft density foam is used.

### Steel Gussets

It is seen that the steel gussets alone can develop more than the needed moment capacity in the corners (local moment only), however, the screws might have trouble in enabling the gussets to attain this capacity.

## RECOMMENDATIONS

### Aluminum

Use .040" to insure resistance against buckling and strength against puncture loads.

### Foam

Use 4 inch core of 2 lb/cu ft density in flat sections to insure against shear and provide superior rigidity and thermal properties.

To maintain a uniform cross section, use a 4 inch thick core in the corners. This shall be of 4 lb/cu ft density foam and rely on help from wood frames and steel gussets to accommodate bending moment.

### Steel Gussets

To get extra help from steel gussets in resisting bending in corners, use 16 screws (14 gauge by 1 1/2 in) instead of 8 screws (14 gauge by 2 in) to insure development of full moment capacity of steel gussets.

### **THERMAL EXPANSION AND CONTRACTION**

Thermal induced stresses in the panels will result from differential expansion and contraction due to the difference in temperatures of the two skins. With the panels tested at Pennsylvania State University, there was no appreciable damage to the panels after 20 cycles of temperature changes over a range of 150°F (65°C). Any difference in temperature in the two skins of aluminum will cause a bowing of the entire panel toward the high temperature side, which is not necessarily the interior of the structure. This deflection may be calculated according to the following equation.

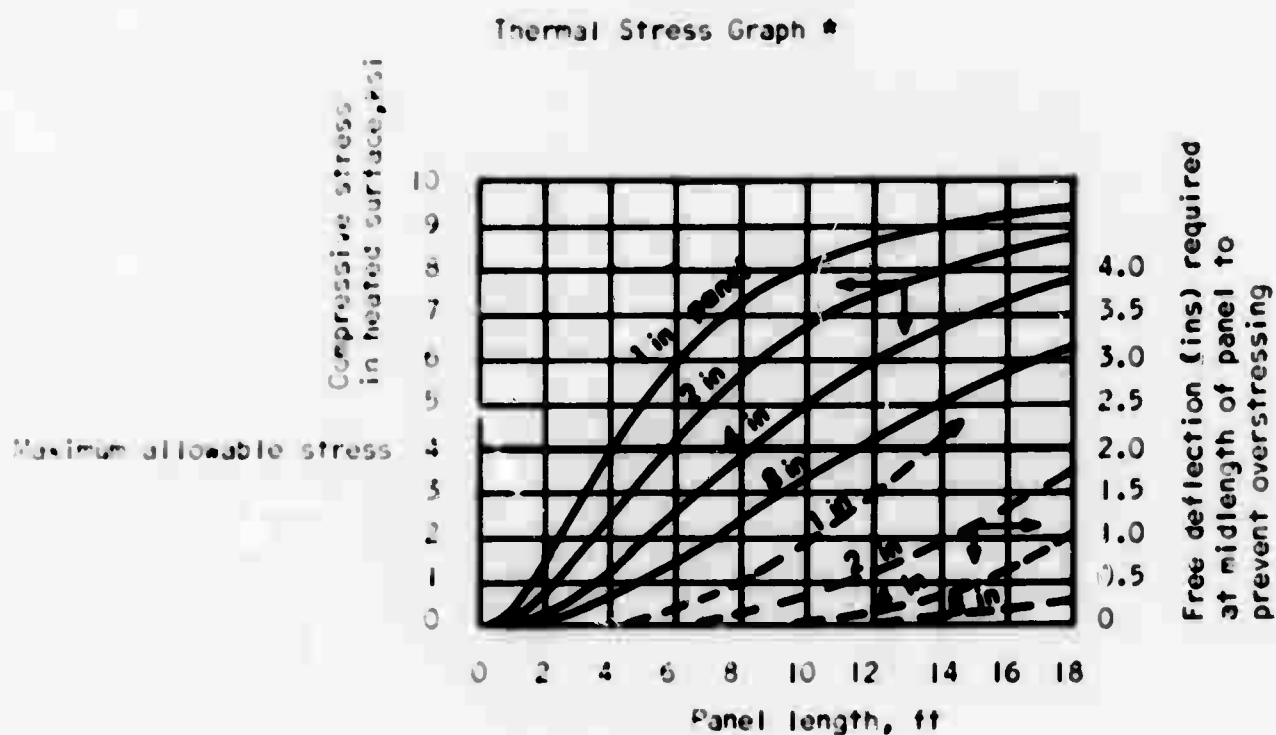
$$\text{Bow}^* \text{ (inches)} = .00021 \frac{L^2 F}{t}$$

L = panel length (feet)  
F = temperature difference of facings (°F)  
t = panel thickness (inches)

To check for possible overstressing of the skins, match the panel thickness and span on the graph to check the resulting stress. If the stress is less than the 4000 psi allowable, then the panel may be attached to the building in any way. If the panel is stressed above the 4000 psi allowable, then the designer may have to alter the thickness, span, or color of the panel.

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\*bowing in an unrestrained panel



- \* 1. Based on a panel with a dark-color exterior face. (Different colors result in variable degrees of heat absorption and reflection, thus affecting the thermal regime and therefore any induced thermal stresses.)
- 2. Based on temperature difference of 100°F between outside and inside face

(Graph from Alcoa Alply Panel brochure)

## THERMAL INSULATION

Insulation values have been determined by the available data on polyurethane foam and aluminum sheeting. A similar type of panel construction done by the Aluminum Company of America (ALCOA) and tested at Pennsylvania State University showed excellent behavior of the foam aluminum sandwich panels under extreme ambient temperatures. The insulation values will remain stable due to the fact that the vapor barrier effect of the closed cell polyurethane foam will not absorb water which would decrease the effectiveness of the insulation.

### Heat Transmission Values

Aluminum - faced panel with designated core and core thickness U-values.\*

Aluminum-faced panel with designated core and core thickness U values		
Panel core thickness, inches	U values, polystyrene	U values, polyurethane
1	.208	.133
1½	.166	.102
2	.113	.071
2½	.088	.060
3	.076	.048
3½	.068	.042
4	.060	.038
4½	.054	.033
5	.048	.029
5½	.044	.027
6	.040	.025
6½	.038	.023
7	.036	.021
7½	.033	.020
8	.030	.018

\*U-values based on still air inside and 15 mph (7 m/sec) wind outside

### APPENDIX III, PROPERTIES OF ALUMINUM AND POLYURETHANE FOAM

#### PROPERTIES OF ALUMINUM SHEETING (Alloy 3003 H16)

##### Physical

Melting range, °F .....	1190-1210
Electrical conductivity at 68°F (20°C), % of CU .....	46
Thermal conductivity at 77°F (25°C), CGS units .....	42
wt per square foot (.040"), psf .....	.57

##### Weather Resistance

Untreated exterior facing .....	good
Treated exterior facing .....	excellent

##### Mechanical (Alclad 3003-H16)

Tensile yield strength, ksi .....	25
Hardness based on Brinell number for 10mm ball at 500 kg force	47
Shear strength, ksi .....	15
Fatigue limit, ksi .....	10
Compression allowable in aluminum face, psi .....	4000
Modulus of Elasticity, psi .....	10,000,000
Safe bearing stress for 1"Ø circle, psi .....	125

#### PROPERTIES OF RIGID POLYURETHANE FOAM

##### Physical

Closed cells, % foam volume .....	90
Water vapor permeability, perm-inch .....	1.5
Water absorption, per sq. foot-surface .....	.05 lb

##### Weather Resistance

Uncovered foam .....	subject to surface deterioration
Covered or coated foam .....	excellent

##### Electrical

Dielectric constant, 1000 cps .....	1.04
Loss tangent .....	.5



**Service**

Service temperature upper limit ..... 180° - 350°F

Service temperature lower limit .....-300°F

**Buoyancy**

Foam density 2 lb/cu ft ..... 60 lbs support/cu ft of foam

**Mechanical**

Density	Strength		
	Compressive	Flexural	Shear
2 lb/cu ft	35 psi	45 psi	28 psi
4 lb/cu ft	82 psi	125 psi	73 psi
10 lb/cu ft	360 psi	540 psi	250 psi

**Thermal**

Density	R factor for 1"	K factor
1.5 - 3	10.0 - 6.7	.10 - .15
8 - 30	2.9 - 1.0	.35 - 1.0

**Fire Retardant**

Rated ..... self-extinguishing

#### APPENDIX IV, LIST OF BROCHURES USED IN FINAL DESIGN

##### Aluminum skin

"Alcoa Alply Panels", 1969 by Aluminum Company of America, Pittsburgh, Pennsylvania

##### Urethane foam

"Urethane Foam Systems ...Value and Versatility" by The Urethane Systems Manufacturers' Committee

"Technical Information, Isonate System CPR 349" by The Upjohn Company Torrance, California

"Technical Bulletin, PolyLite (R) Polyurethane Resin" by Reichhold Chemicals, Inc., Azusa, California

##### Extruded aluminum corners

"Alcoa Product Data, Standard Items", July 15, 1970, by Aluminum Company of America, Pittsburgh, Pennsylvania

##### Aluminum rivets

"Southco Drive Rivets, R-71" by Southco, Inc., Lester, Pennsylvania

##### Form panels

"Concrete Forming Equipment", 1969 by Symons Mfg. Company, Des Plaines, Illinois

##### Buckle connections

"Bassick Clamp Fasteners, Catalog No SCF-70" by Stewart-Warner Corporation Bridgeport, Connecticut

##### Lashing rings

"Refrigerated Container Wall Lashing Ring with Controlled Breakage" by J. N. Blair Limited, Market Harborough, Leics., England

##### Neoprene glazing gaskets

"Stanlock glazing gaskets" by The Standard Products Co., Port Clinton, Ohio

Insulating glass

"Glass for Construction", Jan. 1970, by Libbey-Owens-Ford Company,  
Toledo, Ohio

Weatherstripping

"Bridgeport Inner-Seal Weatherstripping", by Bridgeport Fabrics, Inc.,  
Bridgeport, Connecticut